Issued September 17, 1914.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,

D. W. MAY, Special Agent in Charge,

Mayaguez, P. R.

Bulletin No. 16.

THE EFFECT OF STRONGLY CALCAREOUS SOILS ON THE GROWTH AND ASH COMPOSITION OF CERTAIN PLANTS.

BY

P. L. GILE,
Chemist,

AND

C. N. AGETON,
Assistant Chemist.

UNDER THE SUPERVISION OF
OFFICE OF EXPERIMENT STATIONS,
U. S. DEPARTMENT OF AGRICULTURE.

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PORTO RICO AGRICULTURAL EXPERIMENT STATION.

[Under the supervision of A. C. True, Director of the Office of Experiment Stations, United States Department of Agriculture.]

Walter H. Evans, *Chief of Division of Insular Stations, Office of Experiment Stations.*

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LETTER OF TRANSMITTAL.

PORTO RICO AGRICULTURAL EXPERIMENT STATION,
Mayaguez, P. R., February 13, 1914.

SIR: I have the honor to transmit herewith a manuscript by P. L. Gile and C. N. Ageton on The Effect of Strongly Calcareous Soils on the Growth and Ash Composition of Certain Plants. In plant production we have tried and measured and weighed many results obtained by methods more or less uncertain and inexact. It is becoming increasingly evident that we must go farther back and seek for principles in order that our efforts may lead to more exact and concordant returns. This bulletin throws some light on the relation of certain elements in plant growth and will prove of value in further researches.

I recommend that this manuscript be published as Bulletin 16 of this station.

Respectfully,

D. W. MAY,
Special Agent in Charge.

DR. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Recommended for publication.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

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INTRODUCTION.

Many soil troubles in Porto Rico appear to be due to an excess of lime or to the acidity attending a deficiency of lime. In a previous bulletin of this station[1] attention was called to the action of an excess of lime in rendering soils unsuitable for the cultivation of pineapples. Besides pineapples, some other crops refuse to grow on the excessively calcareous soils, or else give evidence of nutritional disturbances by the chlorotic appearance of their leaves. Since a considerable portion of the arable land of Porto Rico is moderately or excessively calcareous it is believed that investigations to determine the cause and cure of these disturbances are important: As a part of such investigations, a study has been made of the effect of varying amounts of carbonate of lime in the soil upon the growth and mineral composition of various plants.

Since the nutritional disturbances of some plants on the excessively calcareous soils are evidently caused by the chemical and not the physical character of these soils, it was thought that a comparison of the ash contents of plants grown on a normal and on a calcareous soil might indicate the nature of the disturbance. The data reported throw some light on this specific problem as well as on the more general subject of the effect of the soil on the ash composition of plants.

PREVIOUS WORK.

ON THE INFLUENCE OF CARBONATE OF LIME ON THE GROWTH OF PLANTS.

There are few quantitative data on the effect of strongly calcareous soils on the growth of plants. The results of ordinary liming experiments, which show the effect of alterations in the soil reaction, do not apply to this investigation, except that plants thriving best on acid soils must be expected to show a depression on strongly calcareous soils.[2]

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[1] Porto Rico Sta. Bul. 11.

[2] Wheeler, H. J., et al., Rhode Island Sta. Rpts. 1893, pp. 224–252; 1894, p. 152; 1895, p. 205; 1896, p. 242; 1897, p. 202; 1898, p. 144; 1899, p. 171; 1900, p. 293. Coville, F. V., U. S. Dept. Agr., Bur. Plant Indus. Bul. 193; U. S. Dept. Agr. Bul. 6.

There is, however, an extensive literature on calciphilous and calcifugous plants, which for the most part consists of observations on the occurrence or nonoccurrence of plants on calcareous soils.[1] These studies, which have afforded rather conflicting results, seem to show that there are a very few plants which never occur naturally on calcareous soils, but the observations do not show with certainty whether this is due to the physical or chemical character of the soils. There are also some culture experiments which show that some plants, as certain varieties of lupines,[2] sphagnum moss,[3] serradella,[4] pineapples,[5] etc., are intolerant of calcareous soils.

The many studies on the chlorosis of fruit trees and grapevines show that many calcareous soils are not adapted for certain trees and vines. A partial review of the literature on lime-induced chlorosis is given in the bulletin of this station referred to above.

On the whole the literature shows that some plants are extremely intolerant of much carbonate of lime in the soil, some are indifferent, and others require considerable carbonate of lime to make their maximum growth.

ON THE INFLUENCE OF CARBONATE OF LIME ON THE ASH COMPOSITION OF PLANTS.

No comprehensive studies have been made to determine whether the mineral composition of different plants is affected in any constant manner by large amounts of carbonate of lime in the soil, but some work has been done along this line.

Fliche and Grandeau analyzed the ash of the maritime pine (*Pinus pinaster*), the chestnut (*Castanea vesca*), and the bean tree (*Cytisus laburnum*), from calcareous and noncalcareous soils. The calcareous soil contained 3.25 per cent of lime in the surface soil and 24.05 per cent in the subsoil, while the siliceous or noncalcareous soil contained 0.35 per cent of lime in the surface soil and 0.20 per cent in the subsoil. The bean tree grew equally well on the two classes of soil, while the chestnut and maritime pine grew well on the siliceous soil, but developed very poorly, showing strong chlorosis, on the calcareous soil. Analyses, by Fliche and Grandeau,[6] of samples from trees of

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[1] Hilgard, E. W., Soils, New York and London, 1906; Proc. Soc. Prom. Agr. Sci., 7 (1886), p. 32. Hoffman, H., Landw. Vers. Stat., 13 (1871), p. 269. Braungart, R., Jour. Landw., 28 (1880), p. 155. Roux, J. A. C., Traité des Rapports des Plantes avec le sol et de la Chlorose Végétale, Paris, 1900. Kraus, G., Boden und Klima auf kleinstem Raum, Jena, 1911. Vogler, P., Ber. Schweiz. Bot. Gesell., 1901, No. 11, p. 63. Engler, A., idem, p. 23. Schimper, A. F. W., Pflanzen-geographie auf Physiologischer Grundlage, Jena, 1898.

[2] Heinrich, R., Mergel und Mergeln, Berlin, 1896. Pfeiffer, T., and Blanck, E., Mitt. Landw. Inst. Breslau, 6 (1911), No. 2, p. 273.

[3] Paul, H., Ber. Deut. Bot. Gesell., 24 (1906), p. 148.

[4] Meyer, D. Die Kalk und Magnesiadungüng, Berlin, 1910, p. 61.

[5] Gile, P. L., Porto Rico Sta. Bul. 11.

[6] Fliche, P., and Grandeau, L., Ann. Chim. et Phys., 4. ser., 29 (1873), p. 383; 5. ser., 2 (1874), p. 354; 5 ser., 18 (1879), p. 258.

the same age, grown on the calcareous and noncalcareous soils, are given in Table I.

TABLE I.—*Ash analyses by Fliche and Grandeau of trees from calcareous and siliceous soils.*

	Maritime pine—branches.		Chestnut.				Bean tree—branches.	
			Leaves.		Wood.			
	Siliceous soil.	Calcareous soil.	Siliceous soil.	Calcareous soil.	Siliceous soil.	Calcareous soil.	Siliceous soil.	Calcareous soil.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Ash in dry matter	1.32	1.54	4.80	7.80	4.74	5.71	1.19	1.39
Phosphoric acid (P_2O_5)	9.00	9.14	12.32	12.50	4.53	4.27	16.74	11.57
Iron (Fe_2O_3)	3.83	2.07	1.07	.83	2.04	1.27	3.05	2.74
Lime (CaO)	40.20	56.14	45.37	74.55	73.26	87.30	27.15	29.23
Magnesia (MgO)	20.09	18.80	6.63	3.70	3.99	2.07	17.76	12.31
Potash (K_2O)	16.04	4.95	21.67	5.76	11.65	2.69	23.77	24.50
Soda (Na_2O)	1.91	2.52	3.86	.66	.00	.28	3.05	12.68
Sulphur trioxid (SO_3)	....	....	2.97	.00	1.43	.64	4.52	3.73
Silica (SiO_2)	9.18	6.42	5.79	1.46	3.08	1.36	3.96	3.24
Chlorin (Cl_2)	....	....	.30	.52	....	.08	....	....

They concluded that the maritime pine and chestnut on the calcareous soils absorbed an undue amount of lime, which caused a diminution in the other elements, notably in potash and iron; the increase in lime and diminution in potash and iron caused the poor growth of these trees on the calcareous soils. They further state that the presence of an excess of lime in the soil appears to be always unfavorable to the absorption of iron. It will be noticed that the bean tree, which grew equally well on the two soils, showed practically the same content of lime, potash, and iron in the ash when grown on the calcareous as when grown on the siliceous soil.

Wolff reports analyses by Zöller, Köchlin, and Röthe of barley seeds, madder roots, and bugle weed from low-lime and calcareous soils.[1] Unfortunately the comparative growths of the plants on the two classes of soil are not given, so the results are not particularly illuminating for our purpose. Nor is it evident that the comparative samples of plants were grown under like climatic conditions. The barley seeds were grown on soils containing 1.55 per cent and 23.04 per cent of $CaCO_3$, but there was no difference in the ash content and ash composition of the seeds from the two soils. The madder roots from the calcareous soils contained one-third as much Fe_2O_3, Cl_2, and SiO_2 and one-half more SO_3 than the roots from the low-lime soil. The bugle weed (*Ajuga reptans*) was grown on soils containing 0.14 per cent of CaO and 37.16 per cent of $CaCO_3$. The plants grown on the calcareous soil differed from those grown on the low-lime soil in containing twice as much magnesia and chlorin, one-third as much silica, and one-fourth as much soda.

[1] Wolff, E. Aschen-analysen. Berlin, 1871, pp. 18, 116, 138.

Malaguti and Durocher [1] determined the lime in the ash of a number of wild plants growing on calcareous and noncalcerous soils and obtained the results given in Table II.

TABLE II.—*Analyses by Malaguti and Durocher of wild plants from calcareous and noncalcareous soils.*

Kind of plants.	CaO in ash of plants grown on—	
	Calcareous soil.	Noncalcareous soil.
	Per cent.	*Per cent.*
Cruciferæ (6 analyses)	35.79	20.12
Leguminosæ (6 analyses)	40.26	28.12
Dipsacaceæ (5 analyses)	38.65	20.63
Salicaceæ, Populus (5 analyses)	68.87	51.16
Average	45.87	30.01

In five species of plants the lime, soda, and potash in the ash were also determined, as shown in Table III.

TABLE III.—*Analyses by Malaguti and Durocher of wild plants from calcareous and noncalcareous soils.*

Species of plant.	CaO in ash of plants grown on—		K_2O in ash of plants grown on—		Na_2O in ash of plants grown on—	
	Calcareous soil.	Noncalcareous soil.	Calcareous soil.	Noncalcareous soil.	Calcareous soil.	Noncalcareous soil.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Brassica oleracea	27.98	13.62	....	....	....	....
Brassica napus	43.60	19.48	12.34	25.42	5.56	3.00
Trifolium pratense	43.32	29.72	9.60	27.20	4.80	1.60
Trifolium incarnatum	36.18	26.68	19.11	28.74	13.80	4.80
Scabiosa arvensis	28.60	17.16	....	....	....	....
Allium porrum	22.61	11.41	40.23	42.44	2.26	2.00
Dactylis glomerata	6.24	4.62	....	....	....	....
Quercus pedunculata	70.14	54.00	11.60	19.83	2.18	Trace.
Average	34.83	22.09	....	....	....	....

Röthe [2] has analyzed the rupture-wort (*Herniaria glabra*) from a silica sand and dolomite sand. The dolomite sand contained about 56 per cent $CaCO_3$ and 43 per cent $MgCO_3$. The silica sand was made up of quartz and feldspar. The plants from the two soils contained about the same amount of crude ash, but the ash of the plant from the dolomite sand differed from the ash of the check plant in containing one-third as much potash, twice as much lime, three-fifths as much iron, three times as much magnesia, one-twelfth as much silica, and one-seventh as much potassium chlorid. The two samples were taken from different localities and it is not stated whether the plants were of the same age or not.

[1] Malaguti and Durocher, Ann. Sci. Nat. Bot., 4. ser., 9 (1858), p. 222.
[2] Röthe, C., Ber. Naturhist. Ver. Augsburg, 1869, p. 145.

Some results secured by Haselhoff [1] in studying the decomposition of certain rocks are interesting in this connection. Peas, beans, lupines, barley, and wheat were grown in rocks powdered to a fineness of 5 to 0.5 millimeter. Two of the rocks used were sandstone (Buntsandstein) and limestone (Muschelkalk). The sandstone contained no carbonate of lime and the limestone about 94 per cent. Barley and wheat, which made almost no growth on any of the rocks, contained no more lime when grown on the limestone than when grown on the sandstone. Peas, beans, and lupines, which made a relatively good growth on the sandstone and a greatly diminished growth on the limestone, contained respectively two, five, and three times as much lime in the dry substance when grown on the limestone as when grown on the sandstone. These results are not conclusive in connection with our work, however, as the plants were grown on powdered rock without any addition of fertilizers. Thus the growth of the plants was limited mainly by the ease with which the different rocks afforded the mineral nutrients, and any effect which the other characteristics of the rocks could have had upon the plant growth was probably obscured. The results, however, when compared with the data in the following pages, where much smaller increases in lime were induced in the plants, suggest the idea that the presence of an abundance of nutrient salts probably decreases the percentage of lime in the ash of plants grown in calcareous soils.

Studies of D. Meyer [2] and Lemmermann et al.[3] give data showing the influence of the lime content of the soil upon the lime content of the plant. The plants were grown in pots with additions of nitrogen, potash, and phosphoric acid.

Lemmermann et al. worked with six soils, five of which contained from 0.08 per cent to 0.85 per cent of CaO, while the sixth soil, evidently calcareous, contained 9.25 per cent of CaO. Rye, barley, and oats, grown on the calcareous soil with 9.25 per cent CaO, contained less lime in the dry substance than when grown on the soils with 0.53 per cent and 0.85 per cent of lime. There was no depression of growth on the calcareous soil as compared with the other soils. Clover grown on the calcareous soil contained the same amount of lime as when grown on the soil with 0.53 per cent CaO. The growths on the different soils were about the same. Mustard grown on the calcareous soil contained the same amount of lime as when grown on the soil with 0.85 per cent CaO, the growths made on the two soils being approximately equal. Vetch grown on the high-lime soil contained more lime than when grown on any of the other soils, although the growth varied but little between the soils containing 0.53 per cent, 0.85 per cent, and 9.25 per cent CaO.

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[1] Haselhoff, E., Landw. Vers. Stat., 70 (1909), p. 53.

[2] Meyer, D., Landw. Jahrb., 39 (1910), Ergänzungsb. 3, p. 254.

[3] Lemmermann, O., et al., Landw. Jahrb., 40 (1911), No. 1–2, p. 173.

Meyer used six soils, five of which contained from 0.1 per cent to 1.03 per cent of CaO, and the sixth, which must have been calcareous, contained 11.62 per cent of lime. Oats and buckwheat both contained less lime in the dry substance when grown on the soil with 11.62 per cent lime than when grown on the soil with 1.03 per cent of lime, although the growth was slightly greater on the calcareous soil. The results with oats, therefore, confirm those obtained by Lemmermann with this crop.

As far as can be generalized from these results, it seems that on strongly calcareous soils many, but not all, plants contain more lime and less iron, potash, and silica than when grown on noncalcareous soils.

PLAN OF THE INVESTIGATION.

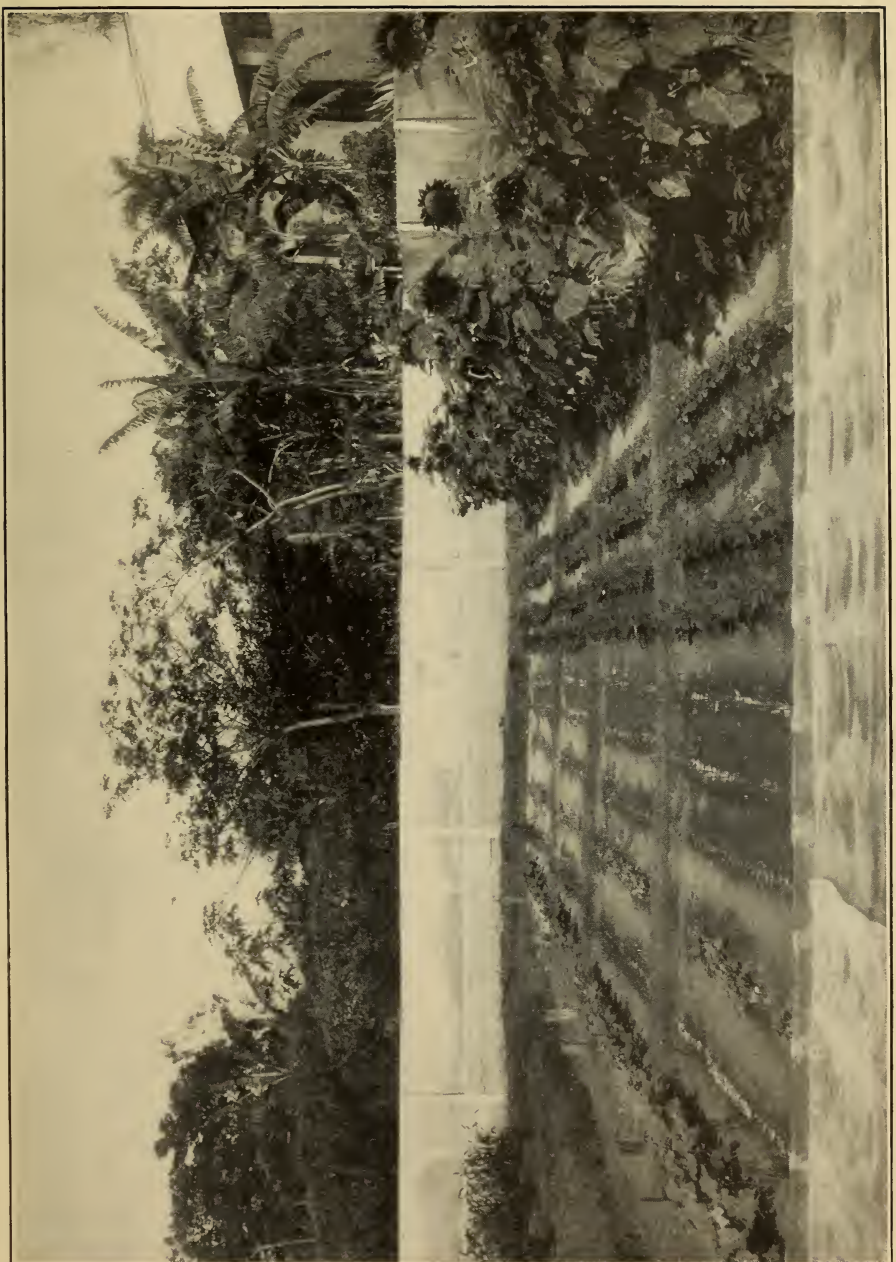
In brief, the plan of the following investigation was to grow several species of plants in adjacent field plats that contained varying amounts of calcium carbonate, and then determine the ash composition of the plants from the different plats. Each species of plant was grown in the plats six different times, and samples of each crop were kept for analysis.

Since the object of the investigation was to determine the effect of the carbonate of lime only on the growth and mineral composition of the plants, it was attemped in the following experiments to make this soil constituent the variable factor affecting the growth. The plats were liberally and equally supplied with fertilizers to insure the plants having sufficient nitrogen, phosphoric acid, and potash available for their maximum growth. When the rainfall was not sufficient the same quantity of water was added to each plat. In regard to sunlight, temperature, and humidity of the atmosphere, the plants in any single experiment were, of course, exposed to identical conditions.

It was not expected that the results obtained with these soils would be absolute for all calcareous soils. For instance, the amount of organic matter in a soil, the water content, and the relative amount of sand and clay influence to a certain extent the degree that carbonate of lime affects the growth, and probably the composition of plants. But, as the variations in organic matter, etc., do not entirely obscure the effect of carbonate of lime on plants unless the amount of lime present is small, it was expected that the results with our soils would show in a general way the effect of carbonate of lime on the growth and composition of the plants tested.

MATERIALS AND METHODS EMPLOYED.

For the purpose of this investigation four plats 10 by 20 feet in area and 2 feet deep were employed, the first plat containing no carbonate of lime, the second approximately 5 per cent, the third 18 per cent, and the fourth 35 per cent. (Pl. I.)



Arrangement of Plats on which Plants were Grown.

FIG. 1.—SWEET CASSAVA GROWN WITH NO LIME, PLAT I.

FIG. 2.—SWEET CASSAVA GROWN WITH 5 PER CENT LIME, PLAT II.

The plats were prepared as follows: Holes of the required size and depth were excavated in a clay soil, leaving a bank 3 feet wide between each plat. These holes were filled with clay, sand, and disintegrated limestone in such proportions as to furnish soils of approximately equal texture and with the above percentages of calcium carbonate. Plat I was made up of approximately 33 per cent clay and 67 per cent sand; Plat II of 34 per cent clay, 60 per cent sand, and 6 per cent limestone; Plat III of 33 per cent clay, 47 per cent sand, and 20 per cent limestone; Plat IV of 32 per cent clay, 30 per cent sand, and 38 per cent limestone. The soil in each plat was made uniform by long-continued mixing. The texture of the soil in Plats I, II, and III was practically equal, that in Plat IV was somewhat heavier although good. As the four plats were surrounded by a ditch, there was no drainage or wash from one plat to the other.

The limestone used was the finely disintegrated material formed by the breaking down of coralline rock.[1] The acid analyses of the soils in the four plats are given in Table IV.

TABLE IV.—*Analyses of the soils of the four plats.*

	Plat I.	Plat II.	Plat III.	Plat IV.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble matter	65.69	59.09	50.74	38.07
Loss on ignition	8.43	10.97	16.17	23.08
Ferric oxid (Fe_2O_3)	11.97	10.82	9.26	6.96
Aluminic oxid (Al_2O_3)	11.39	12.78	12.11	9.10
Lime (CaO)	1.03	4.06	10.90	21.24
Magnesia (MgO)	1.37	1.65	.79	1.51
Potash (K_2O)	.10	.21	.15	.17
Phosphorus pentoxid (P_2O_5.)	.09	.07	.05	.09
Total	100.07	99.65	100.17	100.22
Nitrogen (N)	.09	.08	.07	.07
Carbon dioxid (CO_2)	.00	2.18	7.84	15.35
Calcium carbonate ($CaCO_3$)	.00	4.97	17.83	34.88
Reaction to litmus	Neutral.	Alkaline.	Alkaline.	Alkaline.

While these soils were of good loamy texture, they were very low in organic matter, and were purposely kept so by removing the roots of the various crops, since in the work previously reported [2] there was evidence to show that in the presence of a large amount of organic matter the carbonate of lime would not exert its characteristic effect on the plants. Nitrogen, potash, and phosphoric acid were applied frequently and in such quantities that the growth of plants was not checked by a lack of these elements in any of the plats. Water was also supplied when the rainfall was insufficient. In these plats the plants were grown under natural conditions of soil temperature, root space, and water supply, and the growths made were fully equal to those obtained under ordinary field conditions.

[1] Analysis and description of this material is given under sample 216 in Porto Rico Sta. Bul. 11, p. 22.
[2] Porto Rico Sta. Bul. 11.

Eight species of plants representing six families were tested in the plats, namely: Rice, soy beans, bush beans, radishes, sunflowers, sweet cassava, sugar cane, and pineapples. Six different crops of each plant were grown at various times during the three years that the investigation was in progress, so the results represent the growth made under average weather conditions. It is believed that the average weights of the six crops represent within an accuracy of about 5 per cent the comparative growths made on the different soils.

Since the purpose of the investigation was to determine the effect of a soil constituent upon the ash composition of the plants, it was necessary to cut the plants before they reached complete maturity. If harvested at complete maturity, variations in the ash induced by the soil might have been obscured by losses in the mineral constituents which take place in the later stages of maturity.[1] Moreover, for our purpose the seeds or fruits from the plants on the different soils were not so important as the stems and leaves, since the ash composition of the seeds is less affected by the composition of the soil than the vegetative portion of the plant. While the mineral matter of the stems and leaves is assimilated from the soil, the mineral matter of seeds comes from a translocation of the mineral matter already in the vegetative parts of the plant.[2]

Soy beans and bush beans were harvested in flower, while the leaves were still sound. Radishes were grown to the proper marketable size and not to seed. Sunflowers were grown until the heads had formed, but were cut before the seeds were filled, in order to secure unwithered leaves. Some of the rice was grown to maturity, while other crops were cut at a very early stage and when the panicles were just appearing. This crop was analyzed at several stages of growth. Sugar cane was grown for 148 days and sweet cassava for 122 days. Pineapples were grown ten months. In preparing the samples for analysis none but sound leaves were used, since the ash content of withered leaves is probably dependent more on the leaching to which they have been subjected than to influences of the soil.

The methods used for the analysis of the plant ashes were essentially those of the Association of Official Agricultural Chemists. The ignition of the dry substance was carried out at a low temperature without the addition of calcium acetate, as the lime in the original substance could be determined more accurately without this addition. Comparative analyses made of the dry substance ignited with and without calcium acetate showed that in the absence of the acetate

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[1] Wilfarth, Römer, and Wimmer (Landw. Vers. Stat., 63 (1905), No. 1-2) have shown that considerable losses of potash and nitrogen occur during the ripening of wheat and barley. Le Clerc and Breazeale (U. S. Dep. Agr. Yearbook, 1908, p. 389) have also shown that there is a loss of mineral constituents, particularly at maturity, due to the leaching action of rain or dew.

[2] See Fittbogen, J., Landw. Vers. Stat., 6 (1864), p. 474; quoted by Dikow, A. von, Jour. Landw., 39 (1891), p. 134.

there was no volatilization of phosphoric acid at the temperature at which the ignitions were made. The separation of lime from iron and alumina was effected by precipitating the iron and aluminum phosphates in acetic acid solution without addition of ferric chlorid, as this method possessed some advantages over the official method.[1] The iron was determined volumetrically with potassium permanganate. An aliquot was twice evaporated with sulphuric acid until fumes of sulphuric acid appeared. The diluted solution was then reduced with iron-free zinc, filtered, and titrated with $\frac{1}{20}$ or $\frac{1}{100}$ normal potassium permanganate. Tests with potassium thiocyanate showed that between the final filtration and titration with permanganate no ferric iron was formed.

For the calculation of the results the sum of the constituents found in the acid solution of the ash was not taken as the amount of carbon-free ash, but the total ash was determined absolutely and the percentages of the various constituents calculated from this determination. The percentages of the constituents in the ash are thus dependent upon the accuracy of the determination of the carbon-free ash, which is probably subject to an error of about one part in a hundred. The inorganic elements present in the dry matter of the plant were calculated by multiplying the percentages in the ash by the percentage of carbon-free ash and dividing by 100. In this process the percentage of ash eliminates itself, so the percentages of the constituents found in the dry substance of the plant are more accurate, being independent of the determination of carbon-free ash.

GROWTH AND COMPOSITION OF VARIOUS PLANTS ON THE CALCAREOUS AND NONCALCAREOUS SOILS.

The growths of the various plants on the different soils and their ash compositions are detailed in the following pages. In all the tables Plat I refers to the check plat, containing no carbonate of lime, and Plats II, III, and IV refer to the plats containing, respectively, 5, 18, and 35 per cent of carbonate of lime.

The results obtained with pineapples are reported in a former bulletin of this station.[2]

BUSH BEANS.

Six crops of bush beans, variety Improved Golden Wax, were grown at various seasons of the year. While the growth made at different seasons varied greatly, plantings in March and April giving the maximum growth, the relative growths made on the different plats appeared to be unaffected by the time of planting. The first crop of beans being grown to seed no data were secured on the weight of the plants, as when the seed were thoroughly mature the plants

[1] A report on this method is given in Porto Rico Sta. Rpt. 1912, p. 21.
[2] Porto Rico Sta. Bul. 11.

had shriveled and many leaves had dropped. Plat I yielded 127 grams of shelled beans, Plat II 123 grams, and Plat IV 157 grams. The five succeeding crops were harvested in flower, while the leaves were still green. The absolute and relative growths made on the different plats are shown in Table V.

TABLE V.—*Growth of bush beans on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Weight of green crops.						Relative weights of crops from different plats (Plat I=100).					
		Crop B (99 plants).	Crop C (63 plants).	Crop D (61 plants).	Crop E (64 plants).	Crop F (32 plants).	Total weight crops B–F.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Average of crops B–F.
	P. ct.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*						
I	None.	2,086	455	753	670	777	4,741	100	100	100	100	100	100
II	5	1,913	510	1,035	740	776	4,974	92	112	138	110	100	110±3
III	18	2,112	557	953	690	695	5,007	101	123	127	103	90	109±5
IV	35	2,855	660	954	615	637	5,721	137	145	127	92	82	117±8

It can be seen that the growth of the bush beans averaged, with allowance for the probable error, at least 5 per cent better on the soils containing carbonate of lime.

Crop B from the four plats was analyzed alone, crops D and F were analyzed together, using a composite sample made up of equal parts of the two crops. The whole plant above ground was used for analysis, stems, flowers, and leaves being finely ground up together. In Table VI are given the percentages of the elements in the carbon-free ash and in the dry substance of the plants from the four plats.

TABLE VI.—*Analyses of bush beans from plats with different amounts of $CaCO_3$.*

CROP B.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I	None.	35.54	10.84	8.14	32.98	1.54	12.05	10.62	3.77	1.15	0.86	3.50	0.164	1.28	4.03
II	5	29.95	12.31	7.39	32.38	1.44	12.85	11.48	3.44	1.41	.85	3.72	.165	1.48	3.62
III	18	26.02	11.15	7.16	31.82	1.22	10.80	11.63	3.03	1.30	.83	3.70	.142	1.26	3.58
IV	35	28.53	10.03	7.02	34.45	.99	8.63	12.05	3.44	1.21	.85	4.15	.119	1.04	3.76

CROPS D AND F.

I	None.	25.91	7.67	8.27	33.82	1.28	10.11	11.20	2.90	0.86	0.93	3.79	0.143	1.13	3.77
II	5	26.82	7.90	8.36	31.85	.96	10.08	11.20	3.00	.89	.94	3.57	.108	1.13	3.85
III	18	28.12	7.23	8.57	36.82	.88	8.97	10.82	3.04	.79	.94	3.98	.095	.97	3.62
IV	35	25.57	6.30	7.94	35.19	.82	8.38	11.73	3.00	.74	.93	4.13	.096	.98	3.76

While the content of ash, lime, phosphoric acid, potash, silica, and nitrogen was practically the same for the two sets of samples analyzed, the magnesia and iron content was higher in crop B than in crops D and F, and it will be noticed that this difference holds for the plants grown on all four soils. These results are rather striking when it is considered that crop B and crops D and F were grown in different years and that no magnesium was added in any fertilizer.

The extent to which the carbonate of lime in the soil influenced the ash composition and amount of inorganic substances in the dry matter of the plants is better shown in Table VII. Here the percentages of the different elements present in the plants grown in Plat I are expressed as 100, and the percentages present in the plants grown in Plats II, III, and IV are expressed relative to 100. Table VII gives only the average result of the three crops analyzed. In calculating the average, twice the value was given to the analysis of the composite sample of crops D and F that was given to the analysis of crop B, so the average result gives an equal value to all three crops, B, D, and F.

Table VII.—*Relative ash composition of bush beans from different plats.*

Plat No.	$CaCO_3$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative ash content of dry substance (percentages in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	Per ct.														
I.....	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	97	107	98	95	81	102	103	99	110	100	98	85	105	98
III...	18	97	98	99	105	72	89	101	97	99	100	105	73	90	94
IV....	35	93	86	93	104	64	79	108	99	92	100	112	69	85	98

From Table VII it is apparent that the chief effect of the carbonate of lime in the soil upon the ash constituents in the dry substance of the bush beans or upon the composition of their ash lay in diminishing the content of iron. The silica content is also considerably diminished in the plants grown on the fourth plat. The content of lime, phosphoric acid, and nitrogen in the dry substance and in the ash is remarkably constant for the plants grown on all four plats.

SOY BEANS.

Six crops of Mammoth Yellow soy beans were grown. The plants were harvested in flower, while the leaves were still sound. The absolute and relative growths made on the four plats are given in Table VIII.

TABLE VIII.—*Growth of soy beans on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Green weight of crops.							Relative weights of crops from different plats (Plat I=100).						
		Crop A (51 plants).	Crop B (62 plants).	Crop C (50 plants).	Crop D (53 plants).	Crop E (23 plants).	Crop F (48 plants).	Total weight crops A–F.	Crop A.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Average of crops A–F.
	Per ct.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*							
I......	None..	785	1,765	930	1,581	746	1,639	7,446	100	100	100	100	100	100	100
II.....	5	605	1,678	788	1,592	662	1,520	6,845	77	95	85	101	89	93	90±2
III....	18	765	1,465	670	1,234	577	1,293	6,004	97	83	72	78	77	79	81±2
IV.....	35	675	1,671	730	1,612	815	1,675	7,178	86	95	78	102	109	102	95±3

The average results show that the best growth of soy beans was made on the plat with no carbonate of lime; there was, allowing for the probable error, an 8 to 12 per cent decrease on Plat II, a 17 to 21 per cent decrease on Plat III, and a 2 to 8 per cent decrease on Plat IV.

Crops A, B, and C were analyzed together in a composite sample containing equal parts of the three crops, and crops D, E, and F were analyzed in another composite sample. The results are shown in Table IX.

TABLE IX.—*Analyses of soy beans from plats with different amounts of $CaCO_3$.*

CROPS A, B, AND C.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I.....	None.	23.91	15.64	10.10	30.55	0.81	7.40	8.78	2.10	1.37	0.89	2.68	0.071	0.65	3.51
II....	5	23.23	15.08	9.80	27.45	.78	9.84	9.05	2.10	1.36	.89	2.48	.071	.89	3.65
III...	18	26.32	14.76	10.72	28.45	.55	8.21	8.70	2.29	1.28	.93	2.48	.048	.71	3.18
IV....	35	25.47	13.72	9.59	28.70	.58	8.34	9.11	2.32	1.25	.87	2.61	.053	.76	3.28

CROPS D, E, AND F.

I.....	None.	20.57	14.01	9.98	34.63	1.24	6.32	9.41	1.94	1.32	0.94	3.26	0.117	0.59	4.17
II....	5	20.21	13.24	0.53	33.60	1.16	7.19	9.70	1.96	1.28	.92	3.26	.113	.70	4.47
III...	18	22.12	12.87	11.83	32.54	1.09	8.32	9.58	2.12	1.23	1.13	3.12	.104	.80	4.13
IV....	35	21.81	12.02	10.35	21.75	.83	6.47	9.95	2.17	1.20	1.03	3.16	.083	.64	4.13

The two samples, composed of three crops each, analyzed very nearly the same. The lime was a little higher and the potash and iron a little lower in crops A, B, and C than in crops D, E, and F. These differences hold for all four plats, so they can hardly be chance variations. It seems probable that they are due to climatic influences which affect the plant directly or through the soil.

In Table X are given the relative ash compositions and the relative amounts of ash constituents in the dry substance of the plants from the different plats, the percentages of the different elements in the plants from Plat I being taken as 100 in each case. The results are an average of the two lots analyzed, given in Table IX.

TABLE X.—*Relative ash composition of soy beans from different plats.*

Plat No.	$CaCO_3$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative amounts ash constituents in the dry substance (amounts present in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	P. ct.														
I.....	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	98	96	96	94	95	124	103	101	98	99	97	99	128	106
III...	18	109	93	113	94	78	122	101	109	93	112	95	79	123	95
IV....	35	107	87	100	93	70	108	105	111	91	104	97	73	113	96

The carbonate of lime in the soil had little more effect in varying the ash content of soy beans than it had on bush beans. As with bush beans, the most notable variation appeared in the regular decrease in the iron content of the plant with increasing amounts of carbonate of lime in the soil. The other variations that occurred are of lesser order, not exceeding 10 per cent except in the case of silica. There was a small but regular increase in the amount of lime in the dry substance of the plant with increasing amounts of lime in the soil; in Plat II, however, the increase was not greater than the probable error. Proportionate to the increase in lime, there was a decrease in the amount of magnesia in the dry substance of the plant with increasing amounts of carbonate of lime in the plats. The remaining constituents in the plants showed no parallelism with the lime content of the soils. The greater amount of silica in the plants grown in the calcareous soil appears anomalous.

SUNFLOWERS.

Six crops of large Russian sunflowers were grown. The plants were harvested when the heads had formed, but before the seeds were fully developed. At this stage the leaves were sound, except a few of the lower ones, which were not included in the sample for analysis.

The absolute and relative growths made on the four plats are given in Table XI. The various parts of the plant were weighed separately, but as no one part appeared to be affected by the lime in the soil more than another, only the weight of the whole plant, except roots, is given in Table XI.

TABLE XI.—*Growth of sunflowers on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Green weight of crops.							Relative weights of crops from different plats (Plat I=100).						
		Crop A (8 plants).	Crop B (10 plants).	Crop C (10 plants).	Crop D (10 plants).	Crop E (10 plants).	Crop F (10 plants).	Total weights. crops A–F.	Crop A.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Average of crops A–F.
	P. ct.	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*							
I.....	None.	17.84	22.51	8.52	10.80	5.30	5.56	70.53	100	100	100	100	100	100	100
II....	5	14.45	21.11	9.06	10.96	6.28	6.75	68.61	81	94	106	101	118	121	104 ± 4
III...	18	14.98	22.26	5.80	9.50	4.79	5.29	62.62	84	99	68	88	90	95	87 ± 3
IV....	35	15.38	23.02	7.57	7.89	5.16	5.33	64.35	86	102	89	73	97	96	91 ± 3

The averages of the relative growths show, with allowance for probable error, a possible increase of 0 to 8 per cent in Plat II, a decrease of 10 to 16 per cent in Plat III, and a decrease of 6 to 12 per cent in Plat IV. The total green weights of the six crops give nearly the same results, except that in Plat II there is a slight decrease instead of an increase over Plat I. The average of the relative growths is probably more accurate than the total weight of the six crops, since the former gives an equal value to each crop grown.

Crop A was analyzed alone, and crops D, E, and F were analyzed together in a composite sample. In each case the leaves and stalks were analyzed separately. The results are given in Table XII.

TABLE XII.—*Analyses of sunflowers from plats with different amounts of $CaCO_3$*

LEAVES—CROP A.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I.....	None.	33.70	11.39	6.22	24.92	0.47	......	15.47	5.22	1.76	0.96	3.86	0.073	......	4.48
II....	5	38.06	10.12	5.54	32.37	.79	......	17.49	6.66	1.77	.97	5.66	.138	......	4.97
III...	18	36.93	11.85	5.54	34.21	.82	......	14.62	5.40	1.73	.81	5.00	.120	......	3.98
IV....	35	......	......	......	......	......	......	......	......	......	......	......	......	......	......

LEAVES—CROPS D, E, AND F.

I.....	None.	25.92	12.18	7.02	30.19	0.31	7.32	14.70	3.81	1.79	1.03	4.44	0.046	1.08	3.78
II....	5	29.37	11.71	6.20	31.24	.38	8.79	16.38	4.81	1.92	1.02	5.12	.062	1.44	3.51
III...	18	29.37	10.95	6.63	28.17	.42	8.72	15.74	4.62	1.72	1.04	4.43	.066	1.37	3.75
IV....	35	30.30	10.37	5.47	30.93	.38	7.46	14.71	4.46	1.53	.80	4.55	.056	1.10	3.88

TABLE XII.—*Analyses of sunflowers from plats with different amounts of $CaCO_3$*—Con.

STALKS—CROP A.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I.....	None.	14.74	8.84	7.68	49.06	0.15	......	10.36	1.53	0.92	0.80	5.08	0.016	......	1.58
II....	5	14.66	8.27	7.25	52.90	.21	......	12.31	1.80	1.02	.89	6.51	.026	......	1.74
III....	18	15.03	8.28	6.77	50.86	.13	......	11.28	1.70	.93	.76	5.74	.015	......	1.29
IV....	35	15.22	8.07	6.83	50.14	.14	......	10.77	1.64	.87	.74	5.40	.015	......	1.33
STALKS—CROPS D, E, AND F.															
I.....	None.	13.11	12.90	6.25	48.60	0.51	1.68	10.31	1.35	1.34	0.64	5.01	0.053	0.17	0.93
II....	5	10.94	10.59	4.82	44.29	.33	1.48	11.81	1.29	1.25	.57	5.23	.039	.17	.92
III....	18	11.34	10.80	6.71	55.63	.41	1.90	10.22	1.16	1.10	.69	5.69	.042	.20	.66
IV....	35	9.71	8.66	4.88	50.51	.34	1.52	10.89	1.06	.94	.53	5.50	.037	.17	.73

The percentage of lime in the ash and in the dry substance of the plant was somewhat higher in crop A than in crops D, E, and F, in all four plats. The ash content was about 50 per cent higher in the leaves than in the stalks. There was about three times as much lime in the leaves as in the stalks, twice as much magnesia, about six times as much silica, and two and a half times as much nitrogen. The potash was some 20 per cent higher in the stalks than in the leaves.

The relative ash compositions and relative amounts of asn constituents in the dry substance of the plants from the different plats are given in Table XIII, the percentages of the different elements in the plants from Plat I being taken as 100 in each case. In Table XIII the results are an average of crops A, D, E, and F.

TABLE XIII.—*Relative ash composition of sunflowers from different plats.*

LEAVES.

Plat No.	$CaCO_3$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative amount ash constituents in dry substance (amounts present in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	P. ct.														
I.....	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	113	94	88	110	134	120	112	127	106	100	123	149	135	98
III...	18	112	94	92	104	145	119	104	117	97	97	108	148	127	97
IV....	35	117	85	78	102	123	102	100	117	85	78	102	122	102	103
STALKS.															
I.....	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	87	85	81	95	84	88	116	102	98	95	110	97	100	102
III...	18	90	87	102	112	82	113	102	92	87	105	114	85	118	74
IV....	35	81	73	81	104	74	90	106	86	76	86	109	94	100	80

The leaves from Plat II contained 27 per cent more lime, 23 per cent more potash, 49 per cent more iron, and 35 per cent more silica than the leaves from Plat I, and an equal amount of magnesia, phosphoric acid, and nitrogen. The leaves from Plat III differed from those of Plat I in containing 17 per cent more lime, 48 per cent more iron, 27 per cent more silica, and 8 per cent more potash; the leaves from Plat IV differed in containing 17 per cent more lime, 15 per cent less magnesia, 22 per cent less phosphoric acid, and 22 per cent more iron.

The stalks from Plat II differed from those of Plat I only in containing 10 per cent more potash; the stalks from Plat III differed in containing 8 per cent less lime, 13 per cent less magnesia, 14 per cent more potash, 15 per cent less iron, 18 per cent more silica, and 26 per cent less nitrogen; the stalks from Plat IV differed in containing 14 per cent less lime, 24 per cent less magnesia, 14 per cent less phosphoric acid, 9 per cent more potash, and 20 per cent less nitrogen.

As the green weight of the stalks averaged twice the green weight of the leaves, it can be seen that the lime content of the combined leaves and stalks from Plat II was a little higher than that from Plat I, while the lime content of the leaves and stalks from Plats III and IV varied little from the lime content of those from Plat I. The ash constituents of the combined leaves and stalks of Plat II differed from the ash constituents of the leaves and stalks of Plat I in containing about 10 per cent more lime, 15 per cent more potash, 20 per cent more iron, and 15 per cent more silica; the combined leaves and stalks from Plat III differed in containing some 8 per cent less magnesia, 10 per cent more potash, 20 per cent more iron, 20 per cent more silica, and 20 per cent less nitrogen; the leaves and stalks from Plat IV differed in containing about 20 per cent less magnesia, 17 per cent less phosphoric acid, and 13 per cent less nitrogen.

RADISHES.

Long Scarlet Short Top radishes were grown to the marketable size, which took about 30 days. Roots and tops were weighed separately, but as the proportion of root to top was unaffected by the different soils only the weights of the whole plants are given in Table XIV.

TABLE XIV.—*Growth of radishes on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Green weight of crops.							Relative weight of crops from different plats (Plat I=100).						
		Crop A (25 plants).	Crop B (22 plants).	Crop C (23 plants).	Crop D (28 plants).	Crop E (21 plants).	Crop F (21 plants).	Total weight crops A–F.	Crop A.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Average of crops A–F.
	Per ct.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*							
I.....	None.	1,037	1,188	1,637	1,987	1,344	1,059	8,252	100	100	100	100	100	100	100
II....	5	1,112	1,263	1,234	1,535	1,288	1,199	7,631	107	106	75	77	96	113	96±5
III...	18	1,012	1,102	1,472	1,832	1,211	1,424	8,053	98	90	90	92	90	135	100±5
IV....	35	1,123	1,254	1,454	2,307	1,581	1,603	9,322	108	106	89	116	118	151	115±6

The growth of radishes seems to be unaffected by the amount of $CaCO_3$ in these soils. Making allowance for the probable error, the growths on Plats I to III were equal and there was a 9 to 21 per cent increased growth on Plat IV.

Crops A, B, and C were analyzed together in one composite sample and crops D, E, and F in another. Leaves and roots were analyzed separately. The results are shown in Table XV.

TABLE XV.—*Analyses of radishes from plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	LEAVES—CROPS A, B, AND C.														
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I.....	None.	21.50	7.70	6.42	22.76	1.84	7.45	18.14	3.90	1.40	1.16	4.13	0.334	1.35	5.69
II....	5	23.79	6.83	6.23	22.94	1.46	5.75	17.80	4.23	1.22	1.11	4.08	.260	1.02	5.63
III....	18	24.00	6.38	6.47	25.37	1.28	6.39	18.15	4.36	1.16	1.17	4.60	.232	1.16	5.16
IV....	35	24.90	5.96	5.94	32.16	1.16	3.79	19.20	4.78	1.14	1.14	6.17	.222	.73	5.00
	LEAVES—CROPS D, E, AND F.														
I......	None.	23.28	7.71	6.60	22.64	1.07	4.82	17.68	4.12	1.36	1.17	4.00	0.189	0.85	5.20
II.....	5	28.26	7.11	7.55	21.61	1.09	4.56	18.15	5.13	1.29	1.37	3.92	.199	.83	5.23
III....	18	27.07	6.06	6.24	20.91	1.19	4.50	19.29	5.22	1.17	1.20	4.03	.230	.87	5.35
IV....	35	23.91	5.52	6.38	25.29	.67	3.13	19.01	4.55	1.05	1.21	4.81	.179	.60	4.97
	ROOTS—CROPS A, B, AND C.														
I.....	None.	4.12	2.74	6.12	53.39	0.35	0.44	21.61	0.89	0.59	1.32	11.54	0.076	0.10	3.13
II....	5	5.13	2.76	6.53	49.72	.33	.70	19.61	1.01	.54	1.28	9.75	.065	.14	3.22
III....	18	4.50	2.52	6.65	56.58	.27	.55	19.83	0.89	.50	1.32	11.22	.054	.11	2.75
IV....	35	4.30	2.44	6.05	57.67	.30	1.00	20.09	.86	.49	1.22	11.59	.060	.20	2.98
	ROOTS—CROPS D, E, AND F.														
I.....	None.	5.24	3.41	6.45	51.02	0.59	1.16	20.02	1.05	0.68	1.29	10.21	0.118	0.23	2.85
II....	5	5.77	3.39	6.50	51.51	.33	.82	19.90	1.15	.67	1.29	10.25	.066	.16	3.05
III. ..	18	5.38	2.90	5.98	51.90	.33	.85	20.88	1.12	.61	1.25	10.84	.069	.18	2.98
IV....	35	5.10	2.94	6.03	50.60	.27	.58	21.55	1.10	.63	1.30	10.90	.058	.12	2.95

The two series of composite samples analyzed very much alike, although the variations between the two analyses from the same plat are greater, in many cases, than the variations between the analyses from any two plats in the same series. This is to be expected, as the six crops were not all grown at the same time.

The effect of the carbonate of lime in the soil upon the ash composition of the plant is shown in Table XVI, where all percentages are expressed relative to the percentages present in the plants from Plat I. The results in Table XVI are the average of the two analyses given in Table XV.

TABLE XVI.—*Relative ash-composition of radishes from different plats.*

Plat No.	$CaCO^{3}$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative amount ash constituents in dry substance (amounts present in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
							LEAVES.								
	Per ct.														
I.....	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	116	91	106	98	91	86	101	117	91	107	99	92	87	100
III...	18	114	81	98	102	91	90	105	120	85	102	106	96	94	97
IV....	35	110	75	95	127	63	58	107	117	79	101	135	67	63	92
							ROOTS.								
I.....	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	118	100	104	97	75	115	95	112	96	99	92	71	105	105
III...	18	106	89	101	104	67	99	98	104	88	99	102	65	94	97
IV....	35	101	88	97	104	66	139	101	101	88	97	104	64	126	100

The amount of lime in the dry substance of the leaves increased about 20 per cent in Plats II, III, and IV. Silica and iron in the dry substance of the leaves decreased irregularly from Plats I to IV, while the magnesia decreased regularly. In the dry substance of the roots there was an appreciable increase in lime in Plat II only; magnesia and iron decreased regularly from Plats I to IV. The amount of ash in the leaves increased slightly from Plats I to IV. The composition of the ash in leaves and roots showed about the same variations as the ash constituents in the dry substance.

Taking the plant as a whole (leaves and roots together), it appears that the plants grown on the plats with $CaCO_3$ differed from the check plants in containing about 12 per cent more lime, 7 to 17 per cent less magnesia, and 15 to 35 per cent less iron.

FIG. 1.—SWEET CASSAVA GROWN WITH 18 PER CENT LIME, PLAT III.

FIG. 2.—SWEET CASSAVA GROWN WITH 35 PER CENT LIME, PLAT IV.

PLATE IV.

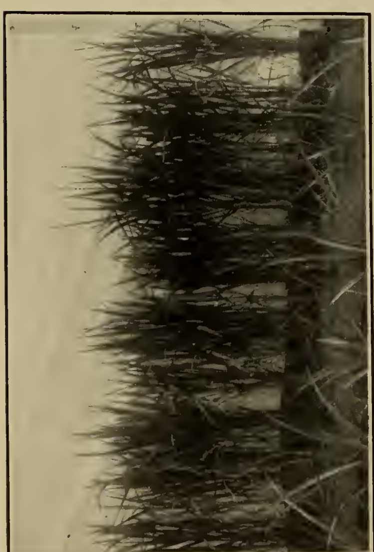

FIG. 1.—RICE GROWN WITHOUT LIME, PLAT I.

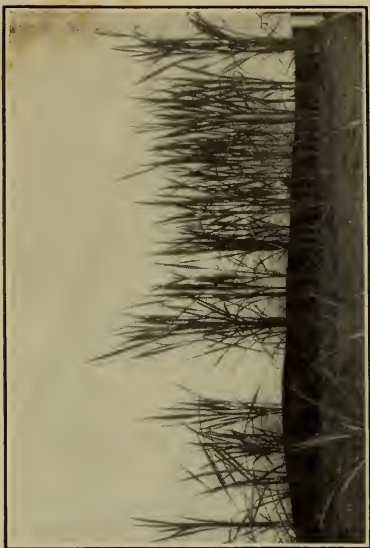

FIG. 2.—RICE GROWN WITH 5 PER CENT LIME, PLAT II.

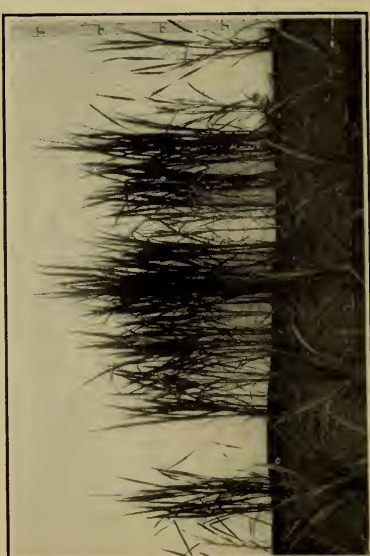

FIG. 3.—RICE GROWN WITH 18 PER CENT LIME, PLAT III.

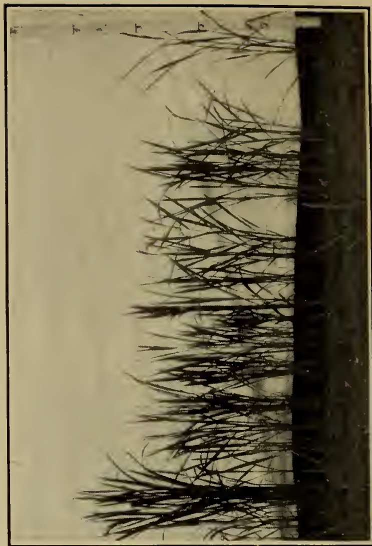

FIG. 4.—RICE GROWN WITH 35 PER CENT LIME, PLAT IV.

SUGAR CANE.

Sugar cane, variety Cristalina, was grown 148 days, which is about one-third of the time necessary for maturity. At the end of this period stalks were forming but practically no leaves had withered. The figures in Table XVII give the weights of the whole plants, leaves and stalks unseparated.

TABLE XVII.—*Growth of sugar cane on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Green weight of crops.							Relative weights of crops from different plats (Plat I=100).						
		Crop A (5 stools).	Crop B (6 stools).	Crop C (6 stools).	Crop D (6 stools).	Crop E (6 stools).	Crop F (6 stools).	Total weights crops A–F.	Crop A.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Average of crops A–F.
	Per ct.	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*							
I.......	None.	15.44	6.06	8.68	8.96	4.30	6.80	50.24	100	100	100	100	100	100	100
II.......	5	13.30	3.48	9.37	9.93	6.06	5.44	47.58	86	57	108	111	141	80	97±8
III......	18	11.58	4.23	8.26	7.09	3.06	4.42	38.64	75	70	95	79	71	65	76±3
IV.......	35	10.58	5.00	6.58	4.28	6.00	7.86	40.30	69	83	76	48	140	116	89±9

On the average the growth of Plat II was practically equal to that on Plat I, but there was a decrease of 21 to 27 per cent on Plat III and a probable decrease on Plat IV of 2 to 20 per cent.

Since the cane when cut had short, poorly defined stalks, only the leaves were used for analysis. Crop A was analyzed alone, and crops B, C, and D were analyzed together in a composite sample. The results are given below.

TABLE XVIII.—*Analyses of sugar-cane leaves from plats with different amounts of $CaCO_3$.*

CROP A.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	Per ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I......	None.	5.13	3.90	7.02	23.78	0.43	56.02	9.32	0.48	0.36	0.65	2.22	0.040	5.22	1.46
II.....	5	5.99	3.82	6.60	22.92	.36	52.71	9.33	.56	.36	.62	2.14	.034	4.92	1.38
III....	18	5.50	4.03	8.87	26.80	.25	53.75	7.90	.43	.32	.70	2.12	.019	4.25	1.22
IV....	35	5.36	3.15	6.94	22.20	.32	53.67	9.46	.51	.30	.66	2.10	.030	5.08	1.53

CROPS B, C, AND D.

I......	None.	7.10	4.25	7.04	22.95	0.36	49.71	7.86	0.56	0.33	0.55	1.80	0.028	3.91	1.34
II.....	5	7.77	4.41	7.91	26.42	.38	47.27	7.78	.60	.34	.62	2.06	.030	3.68	1.40
III....	18	7.97	5.39	8.89	26.86	.58	45.51	7.36	.59	.40	.65	1.98	.043	3.35	1.40
IV....	35	6.76	5.72	8.24	21.71	.39	50.32	8.10	.55	.46	.67	1.76	.032	4.08	1.43

Crop A ran somewhat higher in silica and total ash than the combined crops B, C, and D, otherwise there was little difference between the two analyses in respect to the amount of ash constituents in the dry substance of the leaves. Considering the percentage composition of the ash, crop A ran higher in silica, while the combined crops B, C, and D, were higher in lime and magnesia.

The average relative composition of the leaves from the different plats is given in Table XIX. In calculating the average of the two analyses given in Table XVIII three times the value was given to analysis B, C, and D, that was given to analysis A, so Table XIX represents the average relative composition of four crops from the different plats.

TABLE XIX.—*Relative ash composition of sugar cane leaves from different plats.*

Plat No.	$CaCO_3$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative amounts ash constituents in dry substance (amounts present in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	Per ct.														
I......	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II....	5	113	101	103	106	95	95	100	112	101	102	105	95	94	100
III...	18	110	115	126	115	110	94	90	98	105	114	102	101	84	94
IV....	35	100	108	108	94	91	99	103	102	111	112	97	95	101	106

The amount of the different ash constituents in the dry substance of the plant appears to be unaffected by the carbonate of lime in the soil; only in the plants from Plat II is there an increase in the amount of lime. The composition of the ash also appears to have been influenced very little by the character of the soil. In Plats II and III, but not in Plat IV, the percentage of lime in the ash of the plants was increased by about 10 per cent. The ash of the plants from Plat III ran a little higher in all the elements except silica. On the whole the carbonate of lime in the soil does not appear to have altered the ash composition of cane leaves in any regular way.

SWEET CASSAVA.

Sweet cassava, when harvested at the end of 122 days, was growing vigorously and had formed some fleshy roots. Six crops were grown at different seasons of different years. While the plants in Plat IV were never chlorotic, at times their leaves were noticeably lighter in color than those of the plants in Plats I and II. (Pl. II.)

Roots, leaves, and stalks were weighed separately, but only the total weight of the crop is given in Table XX, as the relative proportions of roots, stalks, and leaves did not vary with the different soils.

TABLE XX.—*Growth of sweet cassava on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Green weight of crops.							Relative weight of crops from different plats (Plat I=100).						
		Crop A (5 plants).	Crop B (5 plants).	Crop C (5 plants).	Crop D (6 plants).	Crop E (5 plants).	Crop F (5 plants).	Total weight crops A–F.	Crop A.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Average of crops A–F.
	Per ct.	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*	*Kgs.*							
I........	None.	10.39	12.98	9.71	8.22	3.08	6.13	50.51	100	100	100	100	100	100	100
II.......	5	10.20	12.93	6.43	6.95	2.74	5.98	45.23	98	100	66	85	89	98	89±4
III......	18	5.74	11.50	5.07	4.60	3.21	5.36	35.48	55	89	52	56	104	87	74±6
IV.......	35	5.76	7.28	3.30	2.72	2.44	4.77	26.27	55	56	34	33	79	78	56±6

The amount of growth made varied greatly with the seasonal conditions; crops E and F, which only made about half the growth of crops A to D, showed a corresponding smaller depression in Plats III and IV. (Pl. III.) From the average of the relative growths it appears that the growth of sweet cassava has been quite markedly depressed by the larger amounts of carbonate of lime and slightly depressed by the smaller amount.

The analyses of the leaves, stalks, and roots of crops A, C, and F are given in Table XXI.

TABLE XXI.—*Analyses of sweet cassava from plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
							LEAVES—CROP A.								
	Per ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I......	None.	30.68	10.10	12.89	30.33	0.80	......	8.37	2.57	0.85	1.08	2.54	0.067	......	4.14
II.....	5	32.14	10.79	11.40	30.67	.93	6.85	8.79	2.83	.95	1.00	2.70	.082	0.60	4.37
III....	18	32.95	11.67	11.63	26.36	.82	8.06	9.12	2.97	1.06	1.06	2.40	.075	.74	4.18
IV	35	33.37	11.16	12.51	27.88	.81	7.98	9.41	3.14	1.05	1.18	2.62	.076	.75	4.37
							LEAVES—CROPS C AND F.								
I......	None.	29.27	6.66	14.01	30.60	0.68	7.16	9.22	2.70	0.61	1.29	2.82	0.063	0.66	4.04
II.....	5	29.92	6.04	13.09	27.16	.49	7.00	9.02	2.70	.54	1.18	2.45	.044	.63	3.94
III....	18	31.52	6.58	14.22	29.41	.46	6.22	9.46	2.98	.62	1.35	2.78	.044	.59	4.08
IV	35	33.67	6.55	13.89	30.80	.46	6.67	8.44	2.84	.55	1.17	2.60	.039	.56	3.93
							STALKS—CROP A.								
I......	None.	25.02	12.35	16.47	36.13	0.74	0.87	6.61	1.65	0.82	1.09	2.39	0.049	0.06	1.88
II.....	5	27.30	11.14	16.83	32.91	.73	1.06	7.31	2.00	.81	1.23	2.41	.053	.08	1.66
III....	18	26.98	11.73	17.01	35.73	.73	1.14	8.12	2.19	.95	1.38	2.90	.059	.09	1.56
IV	35	27.10	12.33	16.53	34.01	.63	1.26	8.53	2.31	1.05	1.41	2.90	.054	.11	1.52

TABLE XXI.—*Analyses of sweet cassava from plats with different amounts of $CaCO_3$*—Continued.

STALKS—CROPS C AND F.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash. Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Ash constituents in dry substance of plant. Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	Per ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I.....	None.	23.86	7.77	16.56	32.60	0.65	0.64	7.93	1.89	0.62	1.31	2.59	0.052	0.05	1.23
II....	5	25.92	6.79	19.91	29.37	.65	1.17	7.90	2.05	.54	1.57	2.32	.051	.09	1.35
III...	18	27.99	7.06	16.87	29.17	.66	.93	8.12	2.27	.57	1.37	2.37	.054	.08	1.16
IV...	35	29.00	8.12	19.47	32.65	.55	.70	7.83	2.27	.64	1.52	2.56	.043	.05	1.14

ROOTS—CROP A.

I.....	None.	12.51	8.82	17.86	45.28	1.42	1.85	3.30	0.41	0.29	0.59	1.49	0.047	0.06	1.48
II....	5	15.00	7.99	15.91	48.60	1.04	1.30	3.48	.52	.28	.55	1.69	.036	.05	1.49
III...	18	14.94	8.44	17.42	47.99	1.72	1.56	3.53	.53	.30	.61	1.69	.061	.06	1.05
IV...	35	18.20	8.89	16.88	42.04	.97	1.47	3.55	.65	.32	.60	1.49	.034	.05	1.04

ROOTS—CROPS C AND F.

I.....	None.	16.48	7.84	16.76	35.86	0.88	1.80	3.70	0.61	0.29	0.62	1.33	0.033	0.07	0.78
II....	5	19.61	7.60	17.25	33.55	.86	1.77	4.14	.81	.31	.71	1.39	.036	.07	.74
III...	18	18.20	7.85	15.83	33.87	.87	2.06	3.70	.67	.29	.59	1.25	.032	.08	.73
IV...	35	21.00	8.71	15.89	33.46	.87	3.45	3.74	.79	.33	.59	1.25	.033	.13	.70

In the leaves and stalks there is a great variation in the magnesia content of crops A and C and F. This difference, which holds for all four plats, may be due either to different climatic conditions existing at the time of growth, or to the crops being cut at different stages of growth, since this plant was grown for a certain number of days. With bush beans similar differences were obtained between the magnesia content of crop B and the combined crops D and F. In this case the difference in the magnesia could not have been due to the crops being cut at different stages of development, since all the crops of bush beans were harvested in flower.

The average relative compositions of the three crops from the different plats are given in Table XXII.

TABLE XXII.—*Relative ash composition of sweet cassava from the different plats.*

Plat No.	$CaCO_3$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative amount ash constituents in dry substance (amounts present in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
					LEAVES.										
	Per ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
I	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II	5	104	99	91	95	94	98	102	105	101	92	97	96	95	102
III ...	18	108	108	96	92	85	87	106	113	114	102	97	91	89	101
IV	35	112	104	98	97	85	93	102	114	107	100	98	88	85	102
					STALKS.										
I	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II	5	109	89	111	91	100	153	106	115	93	117	96	103	157	99
III	18	113	93	103	94	101	138	113	126	104	116	107	112	155	89
IV	35	115	103	109	97	85	127	114	130	116	123	110	97	142	87
					ROOTS.										
I	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II	5	120	94	96	101	86	84	109	130	102	104	109	93	92	98
III	18	115	98	96	100	110	99	104	120	102	99	104	114	107	83
IV	35	136	106	95	94	84	136	105	145	112	99	97	86	135	80

The amount of total ash in the leaves, stalks, and roots increased in all the lime plats by percentages varying between 2 and 14 per cent. The amount of lime in the dry substance of the plant increased with the amount of lime in the soil in contradistinction to bush beans. Magnesia increased with the lime, although in smaller proportion. Phosphoric acid and potash remained practically constant in the plants from all the plats, but in the stalks from Plats II and IV there was an appreciable increase in the phosphoric acid. In the case of the leaves there seemed to be a tendency for the iron content to diminish with the increase of carbonate of lime in the soil, but in the stalks and roots the iron content, though a little irregular, tended to be constant. For the plant as a whole, the iron content was little affected by the different soils, except for a small depression in the plants from Plat IV. The nitrogen content of the leaves was constant for all four plats. The nitrogen contents of the stalks and roots from Plat II were the same as the check, while there was a depression in the nitrogen contents of the stalks and roots from Plats III and IV.

UPLAND RICE.

Of the seven crops of rice grown, six were grown for periods ranging from 84 to 129 days and one for only 25 days. The crop grown for

25 days was not included in the average of relative growths. At 84 days heads were just appearing, and at 129 days the heads were well filled out in the check plat. The data on the relative growths are given in Table XXIII.

TABLE XXIII.—*Growth of rice on plats with different amounts of $CaCO_3$.*

Plat No.	$CaCO_3$ in soil.	Green weight of crops.								Relative weights of crops from different plats (Plat I=100).							
		Crop A (29 plants, 123 days' growth)	Crop B (43 plants, 84 days' growth).	Crop C (39 plants, 102 days' growth).	Crop D (61plants, 102 days' growth).	Crop E (40 plants, 129 days' growth).	Crop F (44 plants, 129 days' growth).	Crop G (364 plants, 25 days' growth).	Crops A–F, total weight.	Crop A.	Crop B.	Crop C.	Crop D.	Crop E.	Crop F.	Crop G.	Average of crops A–F.
	Per ct.	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*	*Gms.*								
I......	None.	2,690	1,076	968	2,190	2,107	2,439	112	11,470	100	100	100	100	100	100	100	100
II.....	5	915	573	549	1,525	1,581	2,031	51	7,174	34	53	57	70	75	83	46	62±5
III....	18	1,364	249	245	254	1,301	1,306	53	4,719	51	23	25	12	62	54	47	38±6
IV....	35	1,067	279	707	1,269	1,235	1,481	55	6,038	40	26	73	58	59	61	49	53±5

The average of the relative growths shows that there was a marked depression on all the calcareous soils, the growth on Plat III being only about a third of that made on the check plat. The plants in Plats II to IV were plainly chlorotic, the chlorosis generally appearing when the plants were about two or three weeks old. Some chlorotic plants in Plats II to IV died, while a few individuals recovered their green color and made almost normal growth. The majority of the plants, however, lived along in a more or less chlorotic condition, making very little growth. The surviving plants in Plats II to IV were somewhat behind the plants in Plat I in flowering and maturing their seed. (Pl. IV.)

This somewhat unequal development of the plants at the end of any specified time made it advisable to analyze the plants at several stages of growth. In the analyses of the crops grown 102 and 129 days only the green stalks and leaves were used, the withered leaves being discarded and the heads not analyzed for reasons mentioned in the first part of this report. The crops grown 84 days had a few undeveloped heads, which were ground up with the green straw in preparing the sample for analysis. The few leaves which were withered at this stage were not incorporated in the sample. In analyzing the crop grown 25 days the whole plant, except the roots, was used, there being no dead leaves. This crop when cut had just commenced to show all the outward effects of the carbonate of lime, the plants being chlorotic and the growth depressed. The difference between the individual plants in the lime plats had not yet become apparent, however, the plants being pretty uniformly affected. The analyses of the various crops are given in Table XXIV.

TABLE XXIV.—*Analyses of rice straw from plats with different amounts of* $CaCO_3$.

Plat No.	$CaCO_3$ in soil.	Analyses of carbon-free ash.						Ash constituents in dry substance of plant.							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
	CROP G (25 DAYS' GROWTH).														
	Per ct.	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*	*P.ct.*
I......	None.	3.22	2.96	6.14	17.50	2.76	60.94	22.29	0.72	0.66	1.37	3.90	0.615	13.58	......
II......	5	7.43	4.04	4.98	19.88	2.11	54.76	17.69	1.31	.71	.88	3.52	.373	9.69	......
III....	18	6.00	3.42	4.65	20.40	1.58	60.49	17.74	1.06	.61	.83	3.62	.280	10.73	......
IV....	35	7.10	3.05	8.05	16.40	1.98	52.72	17.10	1.21	.52	1.38	2.80	.339	9.02	......
	CROP B (84 DAYS' GROWTH).														
I......	None.	3.07	3.34	4.84	24.00	0.31	61.92	18.18	0.56	0.61	0.88	4.36	0.057	11.26	1.87
II......	5	3.27	4.00	5.82	15.89	.34	57.31	19.13	.63	.77	1.11	3.04	.065	10.96	1.93
III....	18	3.92	4.06	10.20	23.46	.27	50.47	16.61	.65	.67	1.69	3.90	.045	8.38	1.99
IV....	35	4.19	3.70	12.04	12.70	.18	50.75	16.82	.70	.62	2.03	2.14	.030	8.54	1.67
	CROPS C AND D (102 DAYS' GROWTH).														
I......	None.	2.64	3.63	5.88	19.76	0.17	62.67	14.18	0.37	0.51	0.83	2.80	0.024	8.89	1.99
II......	5	3.96	4.47	6.85	24.24	.21	56.64	13.44	.53	.60	.92	3.26	.028	7.61	2.44
III....	18	5.25	5.36	7.59	26.13	.29	52.08	12.90	.68	.69	.98	3.37	.037	6.72	3.03
IV....	35	4.51	4.61	6.82	25.26	.30	53.38	13.35	.60	.62	.91	3.37	.040	7.13	2.71
	CROPS E AND F (129 DAYS' GROWTH).														
I......	None.	2.07	3.77	4.31	19.28	0.10	65.18	14.31	0.30	0.54	0.62	2.76	0.014	9.33	1.54
II......	5	2.49	4.72	3.23	24.03	.11	60.68	12.51	.31	.59	.40	3.01	.014	7.59	1.91
III....	18	3.83	4.37	3.11	23.20	.12	62.12	10.91	.42	.48	.34	2.53	.013	6.78	1.83
IV....	35	3.35	4.22	3.44	23.04	.11	62.32	11.92	.40	.50	.41	2.75	.013	7.43	1.63

It is probable that of all the analyses that of crop G, grown 25 days, gives the most accurate comparison of the effect of the carbonate of lime on the mineral nutrition of the plant. As already mentioned, the plants in the lime plats were somewhat slower in maturing than those in the check. Accordingly the analyses of the 84, 102, and 129 day plants from the four plats would show variations in the ash composition that were induced partly by the chemical character of the soil and partly by the stage of maturity. The analyses of crops B and F also tend to show the ash composition of the normal or average plant in Plat I and of the resistant individuals in Plats II to IV, for in the lime plats the greater portion of the sample was afforded by the few resistant individuals which grew well; the plants which were most affected died and did not appear in the sample. Sample G, however, taken at 25 days, includes the less resistant plants and catches them all at practically the same stage of maturity and yet at a time when their nutrition has been sufficiently disturbed to be manifest.

As the different crops were grown at various seasons of different years, as well as to different stages of maturity, one is hardly justified in comparing the different analyses to see how the ash composition of rice straw varies with its development. It appears, however, that there is a constant decrease in the percentage of iron as the plant approaches full maturity.

The relative composition of the different crops from the four plats is shown in Table XXV.

TABLE XXV.—*Relative ash composition of rice straw from the different plats.*

Plat No.	$CaCO_3$ in soil.	Relative composition of ash (percentages in plants from Plat I=100).						Relative amounts ash constituents in dry substance (amounts present in plants from Plat I=100).							
		Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Carbon-free ash.	Lime (CaO).	Magnesia (MgO).	Phosphoric acid (P_2O_5).	Potash (K_2O).	Iron (Fe_2O_3).	Silica (SiO_2).	Nitrogen (N).
CROP G (25 DAYS' GROWTH).															
	Per ct.														
I......	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	......
II.....	5	231	136	81	114	76	90	79	182	108	64	90	61	71	......
III....	18	186	116	76	117	57	99	80	147	92	61	93	46	79	......
IV....	35	220	103	131	94	72	87	77	168	79	101	72	55	66	......
CROP B (84 DAYS' GROWTH).															
I......	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II.....	5	107	120	120	66	110	93	105	113	126	126	70	114	97	103
III....	18	128	122	211	98	87	82	92	116	110	192	89	79	74	106
IV....	35	136	111	249	53	58	82	93	125	102	231	49	53	76	89
CROPS C AND D (102 DAYS' GROWTH).															
I......	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II.....	5	150	123	116	123	124	90	95	143	118	111	116	117	86	123
III....	18	199	148	129	132	171	83	91	181	135	118	120	154	76	152
IV....	35	171	127	116	128	176	85	94	162	122	110	120	167	80	136
CROPS E AND F (129 DAYS' GROWTH).															
I......	None.	100	100	100	100	100	100	100	100	100	100	100	100	100	100
II.....	5	120	125	75	125	110	93	88	103	109	65	109	100	81	124
III....	18	185	116	72	120	120	95	76	140	89	55	92	93	73	119
IV....	35	162	112	80	119	110	96	83	133	93	66	100	93	80	106

The youngest crop, G, seems to show more disturbance in its ash composition than the other crops. In this crop the most marked effect of the carbonate of lime upon the plant ash has been in greatly increasing the amount of lime and in diminishing the amount of iron, total ash, and silica. The same, although less marked, variations occur in crop B as in crop G. Crops C to F on the lime plats also show in their ash composition a great increase in lime and a diminution in total ash and silica, but no diminution in iron.

The percentage of magnesia in the ash is higher in the plants from the lime plats than in the check plants in all the crops. The phosphoric acid, potash, and nitrogen show great irregularity, the plants from the lime plats being sometimes much higher and sometimes much lower in these elements than the check plants.

GENERAL SUMMARY OF EXPERIMENTAL RESULTS.

THE EFFECT OF CARBONATE OF LIME ON THE GROWTH OF PLANTS.

The average relative growths of all the plants on the four plats are shown in Table XXVI.

TABLE XXVI.—*Average relative growths made on the plats by the different plants.*

[Growth made on Plat I=100.]

Plat No.	$CaCO_3$ in soil.	Bush beans.	Soy beans.	Sun-flowers.	Radishes.	Sugar cane.	Sweet cassava.	Rice.
	Per cent.							
I	None.	100	100	100	100	100	100	100
II	5	100±3	90±2	104±4	96±5	97±8	89±4	62±5
III	18	109±5	81±2	87±3	100±5	76±3	74±6	38±6
IV	35	117±8	95±3	91±3	115±6	89±9	56±6	53±5

After making allowance for the probable error of the average results, it appears that the growth of bush beans and radishes was certainly not depressed on the calcareous soils, but possibly slightly increased. Soy beans, sunflowers, and sugar cane were little affected in their growth by the calcareous soils of Plats II and IV, but on Plat III their growth was unmistakably diminished, the decreases being four to nine times the probable error. The growth of sweet cassava was slightly decreased on the moderately calcareous soil of Plat II (Pl. II, fig. 2) and strongly decreased on the more limy soils of Plats III and IV (Pl. III). The growth of rice was greatly depressed on all the lime plats (Pl. IV). In brief then, the tolerance of the plants for the different amounts of carbonate of lime was as follows: Bush beans and radishes were unaffected even by 35 per cent of $CaCO_3$; sunflowers, soy beans, and sugar cane were somewhat affected by 18 per cent of $CaCO_3$; sweet cassava was somewhat affected by 5 per cent of $CaCO_3$ and markedly by 35 per cent; rice and pineapples were greatly affected by 5, 18, and 35 per cent of $CaCO_3$.

Rice and pineapples were the only plants that became chlorotic on the calcareous soils, although the other plants whose growth was but little affected were often a somewhat lighter green on the lime plats than on the check. In the case of soy beans, sunflowers, sugar cane, and rice it will be noted that the greatest depression in growth occurred on Plat III, with 18 per cent of $CaCO_3$ rather than on Plat IV with 35 per cent of $CaCO_3$. As mentioned on page 13, Plat IV,

although of good texture, was heavier than Plats I to III. This heavier physical condition may have influenced the action of the carbonate of lime, or the lime and physical condition of the soil may have affected the plant growth independently and oppositely. It seems more probable, however, that the physical condition of the soil influences the effect of the carbonate of lime upon the plant.

Hilgard observed that "the greater the clay percentage in a soil the more lime carbonate it must contain in order to possess the advantages of a calcareous soil."[1] And in the course of certain other experiments with rice, not reported here, where rice was grown on calcareous soils, we observed that on the heavier calcareous soils the growth was not depressed so much as on the more sandy soils.

THE EFFECT OF CARBONATE OF LIME ON THE ASH COMPOSITION OF PLANTS.

The extent to which the carbonate of lime in the soil influenced the composition of the ash and the quantities of ash constituents in the dry substance of the various plants is shown in Tables VII, X, XIII, XVI, XIX, XXII, and XXV.

In summarizing the effect of the carbonate of lime in the soil upon the ash composition of the plant, it is assumed that the differences in ash composition, which occur between the plants grown on the check and calcareous soils, have been induced by the soil. This assumption is justifiable in so far as other factors tending to induce variations in the ash, such as differences in climate and differences in maturity of the plant, have been equalized or eliminated. As pointed out in the previous pages, it is believed that in growing the plants and taking the samples these factors have been equalized, except in the case of the samples of rice grown 84, 102, and 129 days. All the analyses of rice are given in Table XXV, but in the following summary only the analysis of the 25-day sample is considered, for the reason given on page 30.

The carbonate of lime in the soil increased the percentage of lime in the ash of rice very markedly. The percentage of lime in the ash of sweet cassava from Plat IV was also markedly increased. Soy beans, sunflowers (combined leaves and stalks), and sugar cane, however, showed very slight increases in the lime of the ash. In the radish plants from the plat with 5 per cent of $CaCO_3$ there was a 17 per cent increase of lime in the ash, while in the ashes of radish plants from plats with 18 per cent and 35 per cent of $CaCO_3$ there were progressively smaller increases of lime. This is analogous to the results of Lemmerman et al. and Meyer (see p. 11) with oats. The lime in the ash of bush beans slightly decreased rather than increased with increasing amounts of $CaCO_3$ in the soil.

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[1] Hilgard, E. Soils. New York and London, 1906, p. 369.

The magnesia content of the ash of rice was considerably increased on the calcareous plats, although the increase was not comparable with that of lime. With sweet cassava and sugar cane the magnesia in the ash was little if at all affected. With radishes, sunflowers, and soy beans there was quite a marked depression in the magnesia content of the ash of the plants from Plat IV and slight depressions in the ashes of plants from Plats II and III. Bush beans showed a depression in the magnesia in the ash in Plat IV only.

The amount of phosphoric acid in the ash did not appear to be affected in any constant manner, in any of the plants tested, by the carbonate of lime in the soil. Variations occurred, but they were irregular, showing no correspondence with the lime content of the soils.

The same tendency to constancy and lack of effect of the carbonate of lime is apparent in the figures for potash.

In regard to the percentage of iron in the ash, bush beans, soy beans, radishes, and rice showed a marked and fairly regular decrease with increasing amounts of lime in the soil. The combined leaves, stalks, and roots of sweet cassava showed a marked decrease in the iron content of the ash in Plat IV only. With sugar cane and sunflower there was a tendency to a constant percentage of iron.

The percentages of silica are irregular, but on the whole they were little affected by the carbonate of lime. Where large variations occurred, the percentages of silica in the plant were very small.

The amounts of nitrogen in the dry substance were fairly constant for all the plants, so it seems very probable that the lime had no effect on the nitrogen. However, in the stalks of sunflowers from Plats III and IV, and in the roots and stalks of sweet cassava from Plats III and IV there were noticeable decreases in the nitrogen; but the leaves of both plants from these plats showed no decrease in the nitrogen.

The amount of total ash in the dry substance was slightly increased in all the plants, except rice, by the calcareous soils. For the most part these increases were only three or four per cent, but they occurred with great regularity with bush beans, soy beans, sunflowers, radishes, sugar cane, sweet cassava, and pineapples,[1] cane leaves from Plat III being the only exception. It thus seems very probable that this is a general effect of carbonate of lime on all these plants except rice.

Practically the same observations as were made on the quantity of lime, magnesia, phosphoric acid, etc., in the ash, apply to the quantities of these elements in the dry substance of the plant. There were some differences, however, between the relative ash compositions and the relative amounts of the ash constituents in the dry substance,

[1] See Porto Rico Sta. Bul. 11, p. 35.

due to the increase in total ash of the plants on the calcareous soils. For instance, the amount of lime in the dry substance of sweet cassava (combined leaves, stalks, and roots) increased in Plats II, III, and IV, while the increase of lime in the ash was marked in the plants from Plat IV only. There were also moderate increases in the amounts of lime in the dry substance of sunflowers (combined leaves and stalks) and radishes (leaves and roots) on Plats II, III, and IV. But it should be noted that these increases were of smaller magnitude on the plats with 18 per cent and 35 per cent of $CaCO_3$ than on the plat with 5 per cent; in fact, on the plat with 35 per cent of $CaCO_3$ the combined leaves and stalks of sunflowers contained little if any more lime than on the check plat. This would seem to point to sunflowers and radishes having a certain regulatory power in the absorption of lime from strongly calcareous soils.

What was true of the effect of the calcareous soils on the quantity of magnesia in the ash of the plants holds also for the effect on the quantity of magnesia in the dry substance with slight modifications. Bush beans and soy beans showed only slight decreases in the quantity of magnesia in the dry substance on Plat IV. With sunflowers and radishes there were slight decreases in the magnesia on Plat III and marked decreases on Plat IV. Sugar cane and sweet cassava on all the calcareous soils contained slightly more magnesia than on the check soil.

The quantities of potash and phosphoric acid in the dry substance of the plants did not seem at all affected by the carbonate of lime. As a whole, the results were fairly constant and where variations did occur they were irregular, pointing to neither an increasing nor depressing effect.

With regard to the amount of silica in the dry substance there was a marked and significant decease with rice only.

The regular variations in ash composition and in quantity of the mineral constituents in the dry substance of the plants that were induced by the carbonate of lime are summarized below:

Bush beans. Decrease in Fe_2O_3 in the ash and dry substance.

Soy beans. Slight increase in CaO, slight increase in MgO, and marked decrease in Fe_2O_3 in the ash and dry substance.

Sunflowers (combined analyses of leaves and stalks). Decrease in MgO and slight decrease in P_2O_5 in the ash. Slight decrease in MgO in the dry substance.

Radishes (combined analyses of leaves and roots). Small increase in CaO, decrease in MgO, and marked decrease in Fe_2O_3 in the ash and dry substance.

Sweet cassava (combined analyses of leaves, stalks, and roots). Increase in CaO, decrease in Fe_2O_3 (Plat IV only) in the ash. Increase in CaO, slight increase in MgO, slight decrease in Fe_2O_3 (Plat IV

only), and slight decrease in N (Plats III and IV only) in the dry substance.

Rice. Large increase in CaO, smaller increase in MgO, and decrease in Fe_2O_3 in the ash. Decrease in total ash. Large increase in CaO, large decrease in Fe_2O_3 and SiO_2 in the dry substance.

Pineapples.[1] Marked increase in CaO and marked decrease in MgO and Fe_2O_3 in the ash. Large increase in total ash and large increase in CaO in the dry substance.

In general the carbonate of lime affected the ash composition of the plants in varying the quantities of lime, magnesia, and iron. All the plants, however, did not show variations in all three of these elements. In regard to the variations in the percentages of these constituents in the ash, the different plants behaved as follows: Bush beans, iron alone decreased; soy beans and radishes, lime increased, magnesia and iron decreased; sunflowers, magnesia decreased; sweet cassava, lime increased; rice, lime and magnesia increased, iron decreased; pineapples, lime increased, magnesia and iron decreased. In regard to the variations in the quantities of these elements in the dry substance of the plant, the results were as follows: Bush beans, decrease in iron; soy beans and radishes, increase in lime, decrease in magnesia and iron; sunflowers, decrease in magnesia; sweet cassava, increase in lime and magnesia, decrease in iron (in Plat IV only); rice, increase in lime, decrease in iron; pineapples, increase in lime. Thus the plants varied qualitatively in regard to which mineral constituents were affected and quantitatively with respect to the degree that they were affected.

THE EFFECT ON GROWTH COMPARED WITH THE EFFECT ON ASH COMPOSITION.

In comparing the effect of the carbonate of lime on the growth of the plant with the effect on the ash composition of the plant, it can be seen that there was not always a parallelism between the two effects. For instance, the decrease in the iron content of bush beans on the calcareous soils was not accompanied by a depression in growth; the slight increase in lime, the slight decrease in magnesia, and the marked decrease in iron in soy beans on the calcareous soils were accompanied by a slight depression in growth, although on Plat III where the growth was most depressed the changes in ash composition of the plant were less marked than on Plat IV where the growth was very slightly if at all depressed. The slight increase in lime, the decrease in magnesia, and the marked decrease in iron in radishes on the calcareous soils were not accompanied by any changes in the growth of the plant. The rather marked depression

[1] Loc. cit.

in growth of sugar cane on Plat III can not be correlated with any changes in ash composition.

Where, however, the growth was very markedly decreased and the plants showed an obvious intolerance for the calcareous soils, as observed with pineapples and rice, the marked decrease in growth was accompanied by marked changes in the ash composition of the plants. The increases in lime in the ash and dry substance of rice and pineapples on the calcareous soils were much greater than the increases in lime induced in the other plants whose growths were not so injuriously affected. The marked decreases in iron in the ash of rice and pineapples were not greater than the decreases in iron in some of the other plants whose growths were not depressed. Next to rice and pineapples the largest increase in lime occurred with sweet cassava in Plats III and IV, and on these plats the growth of the plants was markedly depressed. Bush beans, soy beans, sunflowers, radishes, and sugar cane, which showed either no decrease in growth or a smaller depression on the calcareous soils than rice, pineapples, and sweet cassava, showed either no increase or a smaller increase in lime in the plant than rice, pineapples, and sweet cassava.

DISCUSSION OF RESULTS.

The results reported seem to point to certain general facts. The individuality of the various plants with regard to the effect of carbonate of lime on their growth is very marked, some plants growing equally well on the calcareous and noncalcareous soils and other plants doing very poorly on the calcareous soils. There is also an equal individuality of the plants in regard to the effect of carbonate of lime on their ash composition. This individuality, shown experimentally, has an important bearing on the much discussed theories regarding the distribution of plants on calcareous and noncalcareous soils.

Of the eight plants tested, only those plants which showed obvious injury and depression in growth from the carbonate of lime showed a notable increase of lime in the dry substance of the plant. Some plants, as bush beans, contained no more lime in the dry substance when grown on the calcareous soil containing 35 per cent of $CaCO_3$ than when grown on the soil that contained no $CaCO_3$, and only 1 per cent of CaO present as silicate. It thus appears that providing there is a certain sufficiency of lime in the soil it is useless to attempt to increase the lime content of some plants by liming.[1]

It is also interesting to note that while the lime content of pineapples increased with the percentage of $CaCO_3$ in the soil, the lime content of sunflowers was greatest on the soil with 5 per cent $CaCO_3$

[1] Considerable applications of soluble lime salts would probably increase the lime content of the plant even when there is a sufficiency of lime in the soil.

and progressively less on the soils with 18 per cent and 35 per cent of $CaCO_3$, and the lime content of bush beans was practically the same on all the soils. Thus with regard to the amount of lime absorbed, pineapples behaved similar to vetch as observed by Lemmermann (see p. 11), sunflowers behaved similar to oats and buckwheat as observed by Meyer (see p. 12), and bush beans behaved similar to clover as observed by Lemmermann.

The individual manner in which the different plants behaved with respect to their growth and ash composition on the calcareous soils is doubtless due to individual differences in the constitution and physiology of the roots. Since Dyer[1] found that the cell saps of various roots differed in their acidity, differences in the assimilative power of various plants for soil constituents have often been attributed to differences in the strength of the acids excreted by the roots of the various plants. But because the cell sap is acid it does not necessarily follow that the roots excrete an acid. Moreover, the only root excretion that has been well established is carbon dioxid. Therefore it does not seem justifiable to attribute the different behavior of the various plants on the calcareous soil to differences in the acid excretions of their roots. In the light of recent investigations on the permeability of the membrane of plant cells it seems more probable that the differences observed were due to differences in the nature or reactions of the cell membrane.

It appears that the diminished growth of some of the plants on the calcareous soil is due to modifications induced in their ash composition by the carbonate of lime. This conclusion is based on two general assumptions, first, that ash analyses show differences in the mineral nutrition of plants, and, second, that the plants which have made the better growth have an ash composition more nearly approaching the optimum. Before detailing the modifications in ash composition that appear to have induced the injury in the plant, these two sources of doubt in the conclusion will be considered.

In the first place, it should be remembered that an ash analysis does not give a moving picture of the ash composition of the plant during growth, but gives a picture of the ash composition at one stage of growth only. As the percentages of the elements in a plant vary considerably according to the stage of development of the plant, the complete picture of any one ash constituent would be represented by a curve. But an ash analysis gives only one point on the curve, so we are really comparing similar curves by points. The ash analyses show differences in the mineral nutrition of the plants if the points compared occupy the same relative position on the curves; that is, if the plants were analyzed at the same stage of maturity. As precautions were taken concerning the maturity of

[1] Dyer, B., Jour. Chem. Soc. [London], 65 (1894), p. 115; Biedermanns Centbl. Agr. Chem., 23 (1894), p. 799.

the plants, the validity of the conclusion is probably not affected by the first assumption.

The second assumption upon which the conclusion is based, namely, that the plants which have made the better growth have an ash composition more nearly approaching the optimum, is subject to considerable doubt because of our uncertainty concerning the factors and laws governing the ash composition of plants in general. A glance at a collection of ash analyses of the same plant shows that the same plant grown under different conditions may make practically the same growth and yet have a very different ash composition. It does not necessarily follow, however, that under like conditions of growth the ash composition of a plant can be varied without affecting the growth.

Some of the conditions affecting the ash composition of plants are known, and among these may be enumerated the following: The humidity, intensity of light, temperature, and all those conditions which may be summarized as climate, the water content of the soil,[1] the character of the soil,[2] the fertilizers applied,[3] the stage of maturity of the plant,[4] and a great number of circumstances, such as the cultivation of the soil, the thickness of the stands,[5] and the time of planting,[6] which affect either the climatic or soil conditions. All these factors, of course, do not affect the ash composition independently, but more or less interdependently, and therefore it is somewhat difficult to isolate and measure the effect of one factor. However, from the studies that have been made, it appears that climatic influences have the greatest effect on the organic and inorganic composition of the plant.[7]

It seems probable that for every set of climatic conditions there is an optimum ash composition of the plant; and that when the ash composition is varied from this optimum, by varying the chemical character of the soil, the amount of nutrients available, etc., the growth is affected. If this is so, variations in the ash composition of plants induced by differences in the character of the soil, under otherwise like conditions of growth, are significant. But variations

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[1] Fittbogen, J., Landw. Jahrb., 2 (1873), p. 353. Langer, L., and Tollens, B., Jour. Landw., 49 (1901), p. 209. Daszewski, A. von, and Tollens, B., Jour. Landw., 48 (1900), p. 223. Wilms, J., and Seelhorst, C. von, Jour. Landw., 46 (1898), p. 413.

[2] Hall, A. D., Jour. Soc. Arts [London], 52 (1904), p. 881; Jour. Agr. Sci. [England], 1 (1905), No. 1, pp. 65–88. Stahl-Schröder, M., Jour. Landw., 52 (1904), p. 193.

[3] Kellner, O., et al., Landw. Vers. Stat., 39 (1891), p. 361. Dikow, A. von, Jour. Landw., 39 (1891), p. 134. Atterberg, A., Jour. Landw., 49 (1901), p. 97.

[4] Tucker, G. M., and Tollens, B., Jour. Landw., 48 (1900), p. 39. Haselhoff, E., and Werner, S., Landw. Jahrb., 44 (1913), No. 4, p. 651. Fliche, P., and Grandeau, L., Ann. Chim. et Phys., 5. ser., 8 (1876), p. 486. Wilfarth, H., Römer, H., and Wimmer, G., Landw. Vers. Stat., 63 (1905), No. 1–2.

[5] Seelhorst, C. von, and Panaotovic, Jour. Landw., 47 (1899), p. 379. Atterberg, A., Jour. Landw., 49 (1901), p. 97.

[6] Stahl-Schröder, M., Jour. Landw., 52 (1904), p. 31.

[7] Lawes, J. B., and Gilbert, J. H., Jour. Chem. Soc. [London], 45 (1884), p. 305. Stahl-Schröder, M., Jour. Landw., 52 (1904), p. 193.

in the ash composition of plants which are at different stages of maturity or grown under unlike climatic conditions are valueless as showing the effect of the character of the soil.

But even under like conditions of climate, water supply, character of the soil, etc., the ash composition of plants can be varied in some directions without affecting the growth appreciably. This involves the question of "luxus consumption." From studies that have been made of the utilization of nitrogen, phosphoric acid, and potash by the plant, it is apparent that when there is an excess of these nutrients present a plant may take up more of these elements than are necessary for growth.[1] If, however, a certain greater amount of these elements is absorbed, the growth is depressed. Hence we may conclude that there is a minimum amount of an element required for a plant to make a maximum growth; that the plant can absorb luxus above this necessary amount without injury, but when the excess absorption exceeds a certain point injury to growth results.

On this basis some changes in ash are significant while others are not. The greater the change in any particular plant, however, the greater the probability that it is of consequence. The same order of change is probably not equally productive of effect on all plants, however, as some plants seem more sensitive to changes in their ash content than others. Nor is the same order of change necessarily significant for all the mineral elements.[2]

The question whether there are certain ratios that should exist between the elements in the ash, also has a bearing on what changes in the ash are significant. While it is well proven that sodium can partially substitute potassium in the plant, it has not been established that there should be a definite ratio between these two bases.[3] According to some investigators, lime and magnesia can substitute each other to a certain extent in the plant,[4] while others are more of the opinion that these elements should be present in a definite ratio. According to Champion and Pellet, the bases are more or less capable of mutual substitution but the sum of their chemical equivalents should be constant, each species of plant having a different constant.[5]

In short, it is reasonably sure that the differences in ash composition of the plants grown on the calcareous soils were induced by the carbonate of lime and not by some climatic or accidental factor. But it is not certain that these differences in ash composition affected the growth, since we have no general knowledge as to what changes in ash composition are indicative of impaired nutrition. The most

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[1] Jordan, W. H., New York State Sta. Bul. 360, p. 76.

[2] In the experiments of Dikow, Wilms, and Atterberg (loc. cit.), the P_2O_5 content of the plants showed less variation than the N and K_2O content.

[3] Hartwell, B. L., and Pember, F. R., Rhode Island Sta. Rpt. 1908, p. 243.

[4] Malaguti and Durocher, Ann. Sci. Nat. Bot., 4. ser., 9 (1858), p. 222.

[5] Champion, P., and Pellet, H., Compt. Rend. Acad. Sci. [Paris], 80 (1875), p. 1588; Biedermanns Centbl. Agr. Chem., 8 (1875), p. 242; 9 (1876). p. 118.

that can be claimed is, that it is probable, where marked alterations in ash composition accompanied diminished growth, that the changes in ash were the cause of the poor growth. For in addition to uncertainty as to what changes in ash composition are injurious, there is the possibility that differences in growth on the calcareous and non-calcareous soils are conditioned simply by the reaction of the soils, and that the soil reaction affects the plant in some other way than through influencing the absorption of mineral nutrients. If this were so, the decreased growth might not be due to but accompanied by modifications in the ash.

Thus, because of uncertainty concerning the laws governing the ash composition of plants there is considerable doubt of the accuracy of the conclusion that the diminished growth of the plants on the calcareous soils is due to modifications in their ash composition induced by the carbonate of lime. With these general doubts in mind, however, it appears that injury from the carbonate of lime, so far as it concerns the ash composition of the plant, may be due to one of the following modifications in the plant:

1. An undue increase in the lime content of the plant or plant ash.
2. A dimunition in the iron content of the plant or plant ash.
3. An increase in the lime combined with a decrease in the iron in the plant ash.

Judging from the ash analyses reported here it seems that the first modification is the significant one, but judging from the results of direct experiments with pineapples the third modification appears more significant. Of course it is possible that the carbonate of lime may injure different plants differently, influencing the ash composition of one plant in one way and another species in another way.

With respect to the assimilation of nitrogen, phosphoric acid, and potash it is evident that the carbonate of lime had no depressing effect. Even in the case of rice and pineapples, where the carbonate of lime plainly caused a nutritional disturbance, the plants grown on the limy soils often showed higher percentages of nitrogen, phosphoric acid, and potash than the check plants. These results are plainly contradictory of a view which has considerable acceptance, namely, that the nutritional disturbances of some plants on calcareous soils are due to a diminished potash content. The fact that fertilization with potash is not a specific for such disturbances also militates against this view. Of course, the results reported do not show whether the carbonate of lime had any effect on the economical utilization of nitrogen, phosphoric acid, and potash, as those were applied abundantly and in available forms.

The results for the phosphoric acid in the ash analyses would seem to contradict the theory of Crochetelle,[1] that the carbonate of lime injures the plant by decreasing the assimilation of phosphoric acid. The experiments of Priainshnikow[2] with different phosphates also contradict Crochetelle's assumption, as the availability of phosphoric acid in mono and dicalcium phosphate, Thomas slag, and iron and aluminum phosphates was not depressed by carbonate of lime, although the availability of phosphoric acid in bone meal and tricalcium phosphate was depressed.

When the results reported here are compared with the results obtained by Fliche and Grandeau with certain trees,[3] striking similarity in some respects is apparent. The bean tree, which was unaffected in growth by the carbonate of lime, was unaffected in its ash composition except for a depression in the magnesia. The maritime pine and chestnut, whose growths were strongly depressed on the calcareous soils, showed a marked increase in lime and a marked decrease in iron and potash in the ash, when grown on the calcareous soils. All these trees contained a greater percentage of ash in the dry matter when grown on the calcareous soils than when grown on the noncalcareous soil. The above results differ from those obtained by us in that a strong depression of potash was noted in the pine and chestnut on the calcareous soils.

The view that the injury to plants grown on calcareous soils does not lie simply in increasing the lime in the plant seems to be borne out by the direct experiments with pineapples and by experiments in progress with rice. It is also the conclusion arrived at by Fliche and Grandeau, and the opinion of Euler that "* * * der schädliche Einfluss des Kalkbodens ein in chemischer Hinsicht indirekter ist."[4] Jost[5] is of a similar opinion. Euler and Jost, however, believe that the indirect action of the lime in injuring the plants lies in depressing the absorption of potash, apparently basing their opinion on the analyses of Fliche and Grandeau. From the results reported here it appears that the indirect action of the lime lies more in affecting the iron absorption than in depressing the potash; since when potash fertilizers are liberally used there is a depression in growth, but no depression in the amount of potash absorbed.

It should be borne in mind that the results reported here do not warrant a decisive conclusion that the diminished growth of all those

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[1] Crochetelle, J., Ann. Sci. Agron., 2. ser., 8 (1902-3), II, p. 43.

[2] Prianishnikow, D., Landw. Vers. Stat., 75 (1911), Nos. 5-6, p. 357.

[3] See p. 8.

[4] Euler, H. Grundlagan und Ergebnisse der Pflanzenchemie. Braunschweig, 1909, pt. 3, p. 153.

[5] Jost, L. Vorlesungen über Pflanzenphysiologie. Jena, 1908, 2. ed., p. 111.

plants which are affected by the carbonate of lime is due to the same change in ash composition. In fact, some quite marked changes in ash composition, as the decrease of iron in bush beans, occur without affecting the growth. And some depressions in growth occur, as sugar cane on Plat III, with practically no change in ash composition. But those plants which showed the greatest injury from the calcareous soils, pineapples and rice, showed the most marked changes in their ash. The significant changes in the ash composition of these plants were apparently the increase in lime and decrease in iron.

SUMMARY.

The results show, in a soil well supplied with nitrogen, phosphoric acid, and potash, the effect of 5, 18, and 35 per cent of carbonate of lime upon the growth and ash composition of bush beans, soy beans, sunflowers, radishes, sugar cane, sweet cassava, rice, and pineapples.

The growths of bush beans and radishes were unaffected even by 35 per cent of $CaCO_3$. The growths of sunflowers, soy beans, and sugar cane, were somewhat depressed by 18 per cent of $CaCO_3$; the growth of sweet cassava was somewhat depressed by 5 per cent of $CaCO_3$ and markedly by 35 per cent of $CaCO_3$; the growths of rice and pineapples were markedly depressed with the appearance of chlorosis, by 5, 18, and 35 per cent of $CaCO_3$.

The carbonate of lime apparently had no effect on the amount of nitrogen, potash, and phosphoric acid contained in the various plants, but did increase slightly the total carbon-free ash in all the plants except rice, and modified either the amount of lime, magnesia, or iron in the ash of all the plants.

On the calcareous soils the lime in the ash of bush beans was not increased, but there was a slight increase in the amount of lime in the ash of soy beans, sunflowers, and sugar cane. On the plat with 5 per cent of carbonate of lime, the lime in the ash of radishes was increased about 17 per cent, but on the plats with 18 and 35 per cent of carbonate of lime the increases of lime in the ash of this plant were progressively less. On the plat with 35 per cent of carbonate of lime the amount of lime in the ash and dry substance of sweet cassava was markedly increased. On all the calcareous soils the amount of lime in the ash and dry substance of rice and pineapples was greatly increased.

Some plants whose growth was little affected by the carbonate of lime (bush beans, soy beans, radishes, and sunflowers) showed marked decreases in the amount of iron or noticeable decreases in the amount of magnesia in the ash, when grown on the calcareous soils.

The plants whose growths were most depressed on the calcareous soils (rice and pineapples) showed the greatest increases in the amount

of lime in the ash and dry substance of the plant, and also a marked decrease in the amount of iron in the ash.

If the plants which have made the best growth have an ash composition nearest the optimum, it would appear from these results as though the diminished growth of the plants most affected on the calcareous soils were due either to (1) an undue increase in the lime content of the plant or plant ash, or (2) an increase in the lime combined with a decrease in the iron in the plant.

From these results alone it would appear as though the first supposition were correct, but from direct experiments with pineapples the second supposition appears more probable.

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